Forest Management Wetland Stewardship Initiative (FMWSI)

Guiding Principles for Wetland Stewardship and Forest Management Technical Report

Ducks Unlimited Canada
2018

The Forest Management and Wetland Stewardship Initiative

Wetlands are prominent features in forests and are often part of interconnected systems that link all forest ecosystems. They help maintain forest productivity (water/ nutrient flow). Many wetlands are flowing systems, making them vulnerable to linear developments, such as roads.

Wetlands, in various forms, are an important component of Canada's commercial forest zone and provide a variety of ecological goods and services (e.g. food, water, timber, air purification, soil formation and pollination) to both the forest industry and society. Due to greater pressures on water resources, there is increasing interest in water and wetland conservation, which is reflected in existing and emerging wetland related policies, forest certification standards, and forest management practices.

The forest sector has taken a lead role in advancing sustainable forestry and best management practices across Canada. DUC has spear-headed multiple wetland conservation initiatives and views the forest sector as a critical and leading industry to ensure wetlands remain a healthy component of Canada's working boreal forest today and into the future. The Forest Management and Wetland Stewardship Initiative (FMWSI) is an innovative approach to advance shared wetland and waterfowl stewardship goals by working together and leveraging resources.

In 2016, DUC launched the FMWSI with a coalition of forestry partners to work together under a three-year collaborative agreement. The FMWSI is a partnership between Ducks Unlimited Canada (DUC), Alberta-Pacific Forest Industries Inc., Canfor, the Forest Products Association of Canada (FPAC), Millar Western Forest Products Ltd., Tolko Industries Ltd., West Fraser, and Weyerhaeuser Company to advance wetland stewardship in the boreal forest through sustainable forest management.

Under the FMWSI, partners identify projects of potential interest and then select, by consensus, projects to focus on. The end goal of each project is to develop tools that forest practitioners can use when working in and around wetlands. So far, partners have selected three priority projects of mutual interest, to be completed over a three-year term. These include:

1. Forestry and Waterfowl: Assessing and Mitigating Risk
2. Guiding Principles for Forest Management and Wetland Stewardship
3. Wetland Best Management Practices for Forest Management: Planning and Operating Practices

The objective of these projects is to advance sustainable forest management with a specific focus on establishing guiding principles and best management practices to conserve wetlands and waterfowl in forest management planning and operations and to complement provincial forest management planning requirement and the needs of forest certification programs.

DUC would like to thank member companies and their representatives for contributing significant time, expertise, and resources to this initiative.

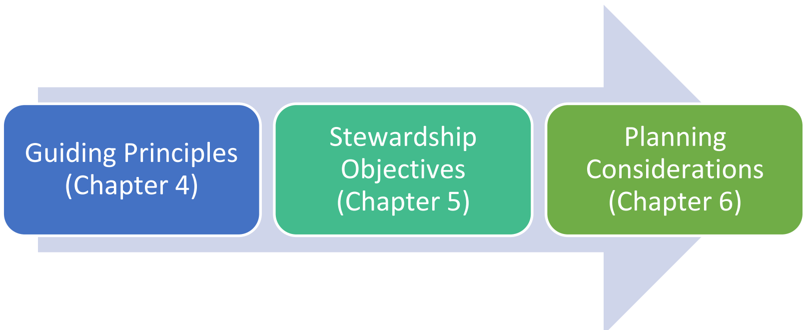
Terms and Conditions

FMWSI members support the contents of this report. However, members are not required to implement the practices and recommendations discussed in this report. Some of the principles and practices may already be in place by member companies, some may be adopted over time, or may not be an appropriate fit for a company based on current practices and approaches, geographic location, and other factors.

Photo Credit Cover Page: Millar Western Forest Products Ltd.

Executive Summary

Chapters One, Two and Three cover an introduction to the document, introduction to boreal wetlands, and describe the intersection of wetlands and forest management. The following chapters cover guiding principles for wetland stewardship (Chapter Four), wetland stewardship objectives to meet those principles (Chapter Five), and avoidance and minimization planning considerations to meet the principles and objectives (Chapter Six).



In Chapters Five and Six we link the material presented in that chapter with the material presented in previous chapter(s). Chapter Seven covers knowledge gaps and recommendations.

Introduction

Wetlands are an important part of Canada's boreal forest and provide ecological, social and economic benefits. These benefits are not limited to wetlands themselves, there is increasing evidence that wetlands and upland forests are interdependent. Sustainable forest management is key to sustaining healthy wetland habitats, and healthy wetlands are key to sustaining productive upland forests. In this document we provide an introduction to boreal wetlands, identify key linkages between boreal wetlands and forest management, and outline four guiding principles along with stewardship objectives and planning considerations that can be applied to meet these principles. This document is aimed at forestry professionals involved in forest management planning at the highest level and the information is intended to assist forest managers in achieving improved wetland stewardship. Wetlands are increasingly a part of legal requirements, certification standards, and social license expectations. Improving awareness and understanding of wetlands and the intersection between wetland stewardship and forest management will help meet these needs.

Wetlands of the boreal forest

Boreal wetlands are diverse and complex systems. There is no single, legally recognized definition of the term 'wetland' that is applicable across all municipal, provincial, and federal jurisdiction in Canada. For the purpose of this document we use the widely accepted Canadian Wetland Classification System (National Wetlands Working Group 1997) definition:

"... land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity which are adapted to a wet environment..."

Classifying wetlands is important for understanding wetland properties and function. Boreal wetlands are typically characterized as organic wetlands or peatlands (bogs and fens) and mineral wetlands (swamps, marshes, and shallow open water). Organic wetlands are characterized by deep organic deposits, typically greater than 40cm. Mineral wetlands are characterized by shallow organic deposits, typically less than 40cm. The Canadian Wetland Classification System recognizes five major wetland classes: bogs, fens, swamps, marshes, and shallow open water. Soil, vegetation, and hydrology are the primary properties used to define these five classes.

Wetlands perform a range of ecological functions that can be grouped into: hydrology, biogeochemical cycling, climate regulation, and habitat. Of particular interest to many industries operating in the boreal are the hydrologic functions. Because boreal wetlands are highly interconnected, industry activities may influence wetland hydrology with potentially far reaching effects to connected wetlands and uplands. Understanding the primary factors influencing water movement in forested environments and how to characterize this water movement can provide valuable information for planning and operational practices.

Forest management and wetland stewardship

Wetlands are an integral component of boreal forest ecosystems and intersect forest management activities in a number of ways. Understanding the benefits and challenges that come from these intersections can help forest managers meet wetland stewardship objectives. Functioning wetlands benefit upland forests by contributing to forest productivity and resiliency, mitigating the effects of upland harvest on waterbodies, influencing wildfire behaviour and patterns, and mitigating effects of climate change. By promoting wetland stewardship, forest managers can help to ensure wetlands continue to provide these benefits on the landscapes they manage.

Wetlands also pose challenges to forest managers, particularly if they are not identified and planned for. Because of high water tables, weak organic soils, and other hydrological and ecological properties, wetlands require additional considerations, time and cost when planning, building and maintaining infrastructure, such as resource roads. Wetlands require additional worker and equipment safety considerations, and increasing legal, certification, and social license obligations require forest managers to consider and address a range of wetland stewardship objectives.

In turn, forest management activities can affect wetlands including potential adverse effects to wetland soils, water quality, and vegetation.

Guiding Principles

Chapter Four describes four guiding principles for wetland stewardship and forest management: (1) maintain wetland quantity, (2) maintain wetland quality, (3) maintain hydrologic processes, and (4) maintain hydrologic connectivity. Working to achieve these principles will support other related values identified under government or certification requirements such as biodiversity, riparian habitats, invasive species control, forest health and productivity, soil productivity, and others.

Stewardship Objectives

Chapter Five describes several wetland stewardship objectives that support the guiding principles. We developed the objectives to address potential adverse effects of forest management activities on wetlands and aligned objectives with current mandatory and/ or voluntary forest management requirements where applicable. Objectives described in this chapter include:

Objective	Page number
1. Maintain surface and subsurface water flow	45
2. Avoid or minimize soil compaction	45
3. Avoid or minimize soil layer disturbance	46
4. Maintain structure and function of riparian and wetland vegetation	47
5. Avoid or minimize site level run-off and erosion	48
6. Prevent sediment and pollutants from entering the wetland	48
7. Avoid or minimize invasive species introduction and/ or spread	49

Planning Considerations

Chapter Six describes avoidance and minimization planning considerations that support the stewardship objectives and guiding principles. The key decisions for successful forest management that promote and support wetland stewardship are made in the planning and design phase.

Avoidance considerations	Page number
A. Map the distribution of wetlands on the landscape by type	57
B. Avoid new disturbances to wetlands by participating in integrated land management planning	59
C. Avoid new disturbances to wetlands by locating new infrastructure near or on existing disturbances and by planning access routes to accommodate future development needs	60
D. Prioritize avoidance	61
Minimization considerations	
E. Consider timing, location and equipment when working in or near wetlands in relation to the following: climate, bedrock and surficial geology, soils, and topography and drainage network	68
F. Consider the location of planned access, harvest, and renewal activities in relation to wetlands and the following: key attributes and flow characteristics, position of wetland in the watershed, and wetland connectivity	70
G. Locate wetland crossings to minimize disturbance	73
H. Consider the wetland type when choosing the wetland crossing	74
I. Schedule activities to occur during favourable weather conditions (e.g. winter operations, shutting down operations during spring runoff or heavy rain events)	75
J. Establish vegetated zones around wetlands	76
K. Establish storage sites and recovery plans for petroleum products and other pollutants	77
L. Minimize invasive species introductions and spread	78

Linking Principles, Objectives and Planning Considerations

The planning considerations can be applied to meet the stewardship objectives and in turn the guiding principles. We discuss a range of tools, approaches, and supporting resources that can be applied to assist with meeting the guiding principles.

Guiding Principles	Stewardship Objectives	Planning Considerations
Maintain wetland quantity	1	All avoidance considerations: A, B, C & D Minimization considerations: E, F & G
Maintain wetland quality	1, 2, 3, 4, 5, 6 & 7	All avoidance considerations: A, B, C & D Minimization considerations: E, F, G, I, J, K & L
Maintain wetland hydrologic processes	1, 2, 3, 4, 5, 6 & 7	All avoidance considerations: A, B, C & D Minimization considerations: E, F, G, I, J, K & L
Maintain regional hydrologic connectivity	1, 2, & 3	All avoidance considerations: A, B, C & D Minimization considerations: E, F, G, H & I

Gaps and recommendations

In Chapter Seven we identify a number of research and knowledge gaps in key topics relating to forest management and wetland stewardship. Monitoring the outcomes of current research in these areas as well as participating and supporting future research will help to close existing gaps and advance knowledge. Topics include:

- Successional dynamics over space and time given historical landscape conditions and projected conditions
- Wetlands and forest fire
- Vegetation regeneration success – e.g., road crossing reclamation
- Wetland hydrologic connectivity
- Wetland hydrologic processes
- Wetland greenhouse gas (GHG) dynamics
- Wetland carbon storage
- Relative value of wetland types
- Effectiveness of minimization strategies

Table of Contents

Chapter One: Introduction

Most Canada's wetlands are found in forested landscapes, and in many parts of the country wetlands make up 50 – 80% of the land base (Figure 1). Wetlands provide ecological, social and economic benefits including providing habitat for plants and animals, sequestering and storing atmospheric carbon, and helping regulate surface, subsurface, and ground water supplies and flow. Recent and ongoing research shows that wetlands and forests are interdependent (*e.g.*, Devito et al. 2012; Petrone et al. 2016; Donnelly et al. 2016; IUFRO 2018); collectively healthy wetlands and healthy upland forests result in functioning forest ecosystems. Sustainable forest management is therefore key to sustaining wetland habitats, and healthy wetlands are key to achieving productive forests.

Wetlands intersect with forest management activities in several ways. Wetlands may influence forest productivity and recovery, affect infrastructure construction and maintenance costs, and can pose risks to workers or public safety. Forest management activities have the potential to affect wetland quality, wetland quantity, and wetland/watershed hydrology. Further, wetland conservation is increasingly part of the legal, certification and social license obligations forest companies are expected to meet.

This document was created at the request of FMWSI companies to align wetland conservation objectives within sustainable forest management frameworks. Specifically, the purpose of this document is to:

- Synthesize information on wetlands in Canada's boreal plains ecozone and the potential effects of forest management activities on these systems
- Provide a foundational framework of guiding principles, objectives, and planning considerations for wetland stewardship that, if implemented, benefit both forest management objectives and wetland stewardship

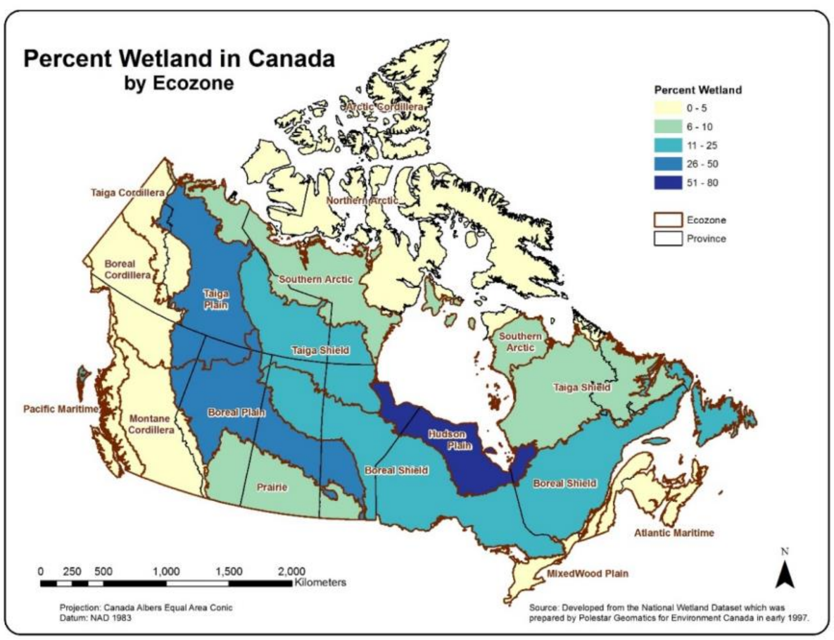


Figure 1. Percent range of wetland in Canada by ecozone.

Overview

This document is intended for forestry professionals involved in forest management planning at the strategic level but can also guide forest planners working at the operational level. The focus of this work is on the boreal plains ecozone (Figure 1, includes parts of Northwest Territories, British Columbia, Alberta, Saskatchewan and Manitoba) because more research has been done on wetlands in this ecozone compared to other regions of the boreal forest. Chapter Two provides an overview of the wetlands of the boreal plains including classification, hydrology, ecological characteristics, and ecosystem goods and services.

The detailed information provided within this report has been summarized in an accompanying Practitioner Guide.

Chapter Three describes links between wetlands, upland forests, and forest management. This information provides context for why it is important to consider wetlands within forest management plans.

The principles and objectives described in Chapters Four and Five provide a framework for wetland stewardship in the context of forest management. The suggested planning considerations described in Chapter Six provide practical strategic planning-level guidance on how to meet the guiding principles and wetland stewardship objectives. Planning considerations were developed based on the best available information and discussions with the forest industry. Gaps identified in Chapter Seven could help direct and prioritize future work. Implementing the information presented in this document will help avoid and minimize potential effects of forest management on wetlands.

DUC developed this document with input from FMWSI members. We worked closely with an advisory committee of three forest industry members representing Alberta Pacific Forest Industries Ltd., West Fraser Timber Company Ltd., and Millar Western Forest Products Ltd. to develop early drafts. All FMWSI members had the opportunity to provide feedback on later drafts and final products.

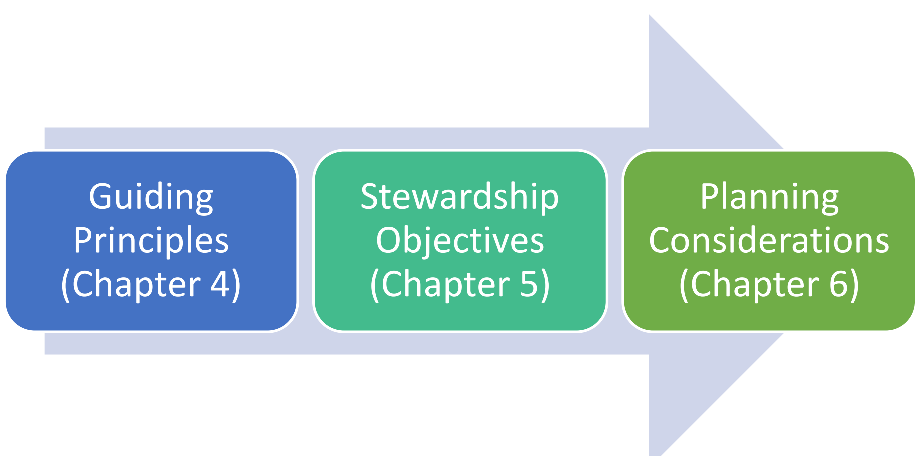


Figure 2. Connections between the Guiding Principles (Chapter Four), Objectives (Chapter Five) and Planning Considerations (Chapter Six).

The information presented in this document is intended to assist forest managers achieve improved wetland stewardship by:

1. enhancing understanding of wetlands in Canada's boreal plains ecozone including the value wetlands bring to the forest sector and society
2. describing interactions between wetlands, upland forests, and forest management
3. establishing wetland stewardship guiding principles, objectives, and planning considerations for the forest industry, that will result in positive environmental outcomes
4. describing practices and tools to consider during forest management planning to help avoid or minimize adverse effects to wetlands
5. identifying knowledge gaps and providing recommendations to fill those gaps

How this document can support forest management needs including regulatory and certification requirements

In many jurisdictions wetland conservation is or is becoming part of the legal, certification, and social license obligations that forest companies are expected to meet. For example, the Alberta Wetland Policy applies to all wetlands in Alberta (Government of Alberta 2013a) and came into effect in the "White or Settled Area" of the province on June 1, 2015 and in the "Green or Forested Area" on July 4, 2016. The policy applies to both crown and private land. Not all wetlands are valued the same and wetland values are based on social and ecological criteria. Under this policy:

- Impacts on wetlands must be avoided where possible
- Where avoidance is not possible, impacts must be minimized
- Where, as a last resort, avoidance and minimization efforts are not possible or effective and permanent impacts will take place, wetlands must be replaced

Most other provinces in Canada do not yet have a wetland policy in place, but have some legal requirements or recommended guidance relating to wetlands, water and watershed conservation. For example, under British Columbia's Forest Planning and Practices Regulation, licensees must maintain natural surface drainage patterns during road construction (Section 39) and must follow certain restrictions when working near most wetlands (British Columbia 2014). Restrictions vary depending on the location and size of the wetland. Other provinces and territories, such as Manitoba and the Yukon, have made commitments to develop wetland policies.

In addition to legislative requirements, all three forest certification systems used in Canada (Sustainable Forestry Initiative, SFI; Canadian Standards Association, CSA; and the Forest Stewardship Council, FSC) include elements of wetland stewardship within their respective forest management standards.

Elements of this document can be integrated into forest management plans to help address and enhance legal and certification requirements. This document will help forest managers plan to avoid wetlands where possible and where avoidance is not possible, to minimize potential adverse effects of forest operations. The principles and objectives described in this document match the terminology and requirements found in the different Canadian forest management certification standards (Appendix 1).

Example The SFI 2015 – 2019 Forest Management Standard specifically includes wetlands within Principle 3, Protection of Water Resources, Objective 3, Protection and Maintenance of Water Resources (SFI 2015). To conform to the Standard, forest companies must develop a program that addresses wetland management and protection during all stages of forest management to maintain water reach, flow and quality.

What this document is not

Disclaimer

This document presents principles, tools, and resources for avoiding or minimizing potential adverse effects to wetlands during forest management operations. Readers are cautioned that this document is a guide that contains selective information based on the best information available at the time of writing. The practices described should not be considered exhaustive or restrictive. Forest managers should select practices and tools to avoid or minimize adverse effects on the basis of the unique, site-specific, on-the-ground conditions and on the feasibility of successful implementation to achieve desired results. Information in this document is subject to change as new practices are developed and evaluated. This document should not be taken as legal advice and where the document differs in any way from applicable legislation, the legislation prevails.

Climate Change

Climate change will affect Canada's boreal in ways we are only beginning to understand. Changes to wetlands and upland forests are a gap that presents a high level of uncertainty and therefore makes it challenging to plan around. In this document we do not directly address the uncertainties associated with climate change; however, we recognize that it is an increasingly important consideration. We recommend that where relevant information exists, forest managers consider this information. There is evidence to suggest that boreal wetlands, and particularly peatlands, will play an important role in mitigating the effects of climate change (Schneider et al. 2016). Boreal peatlands hold significant carbon stores and are important water sources for adjacent uplands and open water wetlands. We will come back to the issue of climate change at the end of this document when we identify gaps and recommendations.

Chapter One Summary

- Canada's boreal forest is a wetland rich landscape. Boreal wetlands provide important ecological, social, and economic benefits.
- Wetlands intersect with forest management activities in a number of ways – influencing forest productivity, affecting infrastructure, and posing risks to worker and public safety.
- The audience for this document is forestry professionals involved in forest management planning at the strategic level; however, content may also be of interest to others involved in forest planning and operations.
- Wetlands are increasingly recognized in legal, certification, and/ or social license obligations. Content from this document can be used to support/ meet regulatory and certification requirements.
- The information presented in this document does not supersede legal responsibilities.
- Climate change and future wetland dynamics are not clearly understood and will respond to changes in the hydrologic cycle.

Chapter Two: Wetlands of the Boreal Forest

Canada is one of the most water rich areas in the world (Wells et al. 2011). In fact, 25% of the world's wetlands are found in Canada with the majority (85%) of these wetlands located in the boreal forest. Wetlands in Canada's boreal forest are as diverse as they are abundant and provide numerous benefits. In this Chapter, we define wetlands, describe the diversity of Canadian wetland types, and outline the goods and services they provide to both Canadian society and the forest industry.

Wetland Definition

The typical image of a wetland is often a shallow, open waterbody surrounded or interspersed with emergent vegetation such as cattail or bulrush. Wetlands that match this description can be found in the boreal forest; however, they make up only a portion of all boreal wetlands. Boreal wetlands are diverse in their form and function. Some wetland types, such as treed swamps, can be mistaken for uplands during dry periods, because of certain ecological characteristics (e.g., tall trees). However, a basic understanding of distinguishing wetland features that can assist with identification:

1. water present above, at, or below the forest floor surface
2. poorly drained soils
3. organisms adapted to living in wet conditions

For more information on wetland definitions used in Canada refer to Appendix 2

There is no single, legally recognized, wetland definition that is applicable across all Canadian jurisdictions. However, the Canadian Wetland Classification System (CWCS; National Wetlands Working Group 1997) provides a widely accepted definition:

"... land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity which are adapted to a wet environment..."

***Figure 3*.** Boreal wetlands frequently occur as parts of large wetland complexes, such as those depicted in the photos above. Note the variation of wetland types that occur over relatively small geographic extents.

Wetlands can vary in size from small local features to large complexes. Wetlands can have areas of open water (less than 2m in depth) or be temporarily dry, and can be treed, shrubby, or open with mosses, sedges or grasses (Figures 4-9 pictures below). Thus, it can sometimes be challenging to differentiate wetlands and uplands, although there are some general terrain, soil, and vegetation indicators that can be used to help:

Wetlands

Figure 4. Example of wetland terrain

Figure 6. Example of wetland soil

Figure 8. Example of wetland vegetation

Uplands

Figure 5. Example of upland terrain

Figure 7. Example of upland soil

Figure 9. Example of upland vegetation

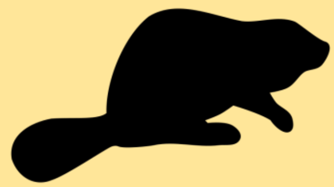
Wetland Ecology

Wetlands can form wherever soil is saturated with water for extended periods of time. Climate, geology, and topography interact to create these saturated conditions. How water moves within and between wetlands, wetlands and uplands, and wetlands and the atmosphere, is influenced by soil type, texture, depth to impermeable layer, parent material, topography, drainage network, and local and regional climate conditions (Devito et al. 2005). These factors also influence wetland abiotic (chemical and physical) and biotic (microbes, plants and animals) ecological functions and these functions can be expressed through ecological features such as:

- soil characteristics
- nutrient cycling and availability
- number and type of plant and animal species found within the wetland

Disturbance and wetland ecology

Disturbances such as wildfire and North American beaver (*Castor canadensis*) also influence the abundance, distribution and type of wetlands present in the boreal forest.



These ecological features can be used to classify wetlands into different types (see Wetland Types).

Wetland ecological functions are defined as the "natural processes (physical, chemical, biological) that are associated with wetlands…" (Hanson et al. 2008) that maintain and sustain wetlands. Hanson et al. 2008 sort wetland functions into four main categories:

- hydrology e.g., storage and release of water
- biochemical cycling e.g., nutrient transformation, biomass and soil production
- climate regulation e.g., carbon sequestration and storage, influence on local regional temperature and precipitation
- habitat

These functions provide valuable goods and services that benefit society (see Benefits of Wetlands) and could be potentially adversely affected by forest management activities as described in later chapters.

Wetland Types

Classification

As mentioned above, wetlands can be classified using ecological features. The CWCS uses soil types, hydrological conditions, and the resulting vegetation communities to differentiate between five major wetland classes: bogs, fens, swamps, marshes, and shallow open waters. These wetland classes can be categorized as organic or mineral wetlands based on soil type and depth of organic deposits. Wetlands can also be classified as open water and aquatic, conveyor, or source based on their expected contribution to run-off and nutrient mobilization (Mertens 2018).

- Organic wetlands or peatlands (bogs and fens) are typically located on flat, poorly drained terrain. These systems are characterized by organic deposits greater than 40 cm deep that build up slowly due to wet, cool, low oxygen conditions.
- Mineral wetlands (swamps, marshes and shallow open water wetlands) are characterized by shallow organic deposits less than 40 cm deep and nutrient rich soils and water. They are a diverse group of wetlands with dynamic water regimes.

Proper and common wetland terminology

Bogs and Fens**:** are often referred to as 'muskeg', these classes may be open/graminoid, shrubby, or treed.

Swamps**:** are a diverse group of wetlands and may be referred to as 'lowlands' and in some parts of the country may be called 'muskeg'. Swamps are the least understood and recognized class of wetlands in the boreal forest.

Marshes and ***Shallow Open Water***: what most people perceive to be wetlands, none of the marsh or open water wetland types are treed. These wetland types are sometimes referred to as 'sloughs' or sometimes 'beaver floods'.

The five boreal wetland classes are described below, for more detailed descriptions of these classes refer to Appendix 2.2 or to wetland identification resources.

Bogs: are nutrient poor peatlands that only receive water through precipitation. They are often characterized as "stagnant" (no to gradual water movement) because some bogs are isolated from groundwater and, under average climatic conditions, do not produce surface run-off. However, like all wetland types, bogs have the potential to move water and during wet periods can act as important water sources to adjacent wetlands and uplands. Bogs often have relatively low plant diversity due to low nutrient availability. Treed bogs tend to be source wetlands, providing water to other parts of the landscape. Open and shrubby bogs tend to be conveyor wetlands, responsible for moving water between sources and sinks.

Fens: are peatlands that receive water through a combination of precipitation, surface runoff and groundwater sources. Because of surface and groundwater inputs they tend to be more nutrient rich than bogs and as a result have greater plant species diversity. Fens can be nutrient rich or nutrient poor depending on water sources and nutrient availability/input. Fens represent a range of hydrologic units depending on vegetation and richness. Treed poor fens are considered 'source wetlands', treed rich fens and shrubby rich and poor fens are considered 'conveyor wetlands', and graminoid rich and poor fens are considered 'open water and aquatic' (Mertens 2018).

Swamps: are mineral based wetlands that may have deeper (e.g., greater than 40cm) peat soils. These wetlands are diverse and are sometimes referred to as lowland forests, forested wetlands, treed swamp forests, wooded swamps, or shrub swamps. They are commonly recognized as shoreline areas of streams, lakes and floodplains. Swamps receive water from run-off, precipitation and groundwater sources with water movement regimes that range from stagnant to dynamic. Swamps can be conveyor or source wetlands depending on whether they are treed (source) or shrubby (conveyor).

Marshes: sometimes called reed swamps or sedge meadows, marshes are often transition zones between open water and shorelines. Marshes receive water from precipitation, run-off, groundwater, and streams. They have mineral soils with shallow organic deposits. Water levels in marshes fluctuate seasonally allowing them to dry out periodically, exposing soils to oxygen, and resulting in a nutrient rich soil substrate that supports the germination of water tolerant emergent plants (e.g., sedges, grasses, rushes, reeds, and cattail). Marshes are 'open water and aquatic wetlands' typically acting more as sinks than as water sources or conveyors.

Shallow Open Waters: often called ponds or sloughs, have a water depth of less than two meters. Open water wetlands receive water from precipitation, run-off, groundwater, and streams. They look like shallow lakes and may have pond-lily or submerged aquatic vegetation in more nutrient rich settings, but are too deep for emergent plants such as cattail and rushes to establish. Open water wetlands are generally permanently flooded but water levels may fluctuate seasonally resulting in exposed mudflats. Marshes are 'open water and aquatic wetlands' typically acting more as sinks than as water sources or conveyors.

These five major types of wetlands can be further classified in a number of different ways and there is no single classification system that is used consistently across the country. Refer to Appendix 2 to learn more about other wetland classification systems.

Seeps, springs, ephemeral draws and vernal pools:

Seeps, springs, ephemeral draws are valuable hydrologic features that may be permanently or seasonally connected to wetlands and which are common features within the boreal forest. In some cases these features may also be wetlands (*e.g.,* an ephemeral draw may be a shrub swamp). Seeps are wet areas where ground water percolates up to the surface; springs are discrete areas where groundwater flows naturally though a rock or soil onto the surface; ephemeral draws are small areas with shallow soil layering that impedes flow and promotes short-term surface saturation with sufficient precipitation and run-off.

Vernal or woodland pools develop in relatively small depressions that temporarily fill with water following spring snowmelt, heavy rainfall or as a result of a high water table. They are generally not hydrologically connected to other wetlands or streams but may be an important water source for surrounding vegetation. These pools may be in a forest stand with a well-developed canopy, making them hard to inventory remotely or predict where they may occur. Vernal pools do not support breeding populations of fish but are important habitats for a variety of wildlife adapted to their conditions (*e.g.,* frogs, salamanders, insects, and fairy shrimp).

Operationally these areas may become sites of concern due to sensitive soils, potential site disturbance and winter thaws. They are usually avoided if detected during pre-harvest surveys or during operations. These sites present good opportunities for retention and wildlife trees.

Wetland complexes

Wetlands can occur as single well defined, and sometimes isolated, features in areas of rolling terrain. In areas with low topographic relief, wetlands are often highly connected resulting in a large expanse or "complex" of several wetlands transitioning from one wetland type to another across the landscape. Several wetland classes can be associated with an open water pond or stream or adjacent to upland sites. Theses wetland riparian areas are typically defined as areas of transition between open water areas and uplands and as moisture and soil conditions change across that transition, several types of wetlands may occur such as emergent and/or meadow marshes, treed or open fens, shrub or conifer swamps or any combination of these. Fen complexes are extensive in Alberta and provide important caribou habitat within identified caribou ranges. Promoting conservation of these features can contribute to achieving other mutually supporting goals, such as caribou conservation.

Wetlands in Forest Planning Inventories

Forest Planning Inventories identify the type, extent and conditions of vegetation, where vegetation exists and what changes are occurring. Vegetation inventories are available across Canada, have typically been developed to a provincial standard, in most areas are done by FMA holders, and have varying degrees of coverage:

- BC Vegetation Resources Inventory (VRI)
- Alberta Vegetation Inventory (AVI)
- Saskatchewan Forest Vegetation Inventory Standard (SFVI)
- Manitoba Forest Lands Inventory
- Canada Land Inventory (CLI)
- Alberta Biodiversity Monitoring Institute's Human Footprint Inventory

For example, the AVI is a photo based digital vegetation inventory that is the current standard used for developing forest management plans in Alberta (AESRD 2006). Wetlands are not specifically interpreted or identified within the AVI (AESRD 2005) and are often fit into the "non – forested vegetated land" that include: closed shrub, open shrub, herbaceous – grassland, herbaceous – forb, and bryophyte. Thus, wetlands, especially those with shallow open water and or that are treed, are often underrepresented in forest landscape assessments completed based on AVI data. Treed wetlands, particularly swamps are included as part of treed stand inventories based on AVI. For more information on forest vegetation inventories, refer to Chapter Six tools.

Wetland flow characteristics

Each wetland class or type has a unique hydrology that is the result of climate, geology, topography and biological drivers (e.g. beaver activity). The bedrock and surficial geology (soil type, texture, strata, depth to impermeable layer, and parent material) in a given region of the boreal zone, along with local topography, influence the development of wetlands over time, along with the extent, permanency, and type of water flow into and out of wetlands (Devito et al. 2012; Gingras et al. 2016).

Figure 10. Primary factors influence water flow in forested environments. Refer to Appendix 3 for additional information on the primary factors that influence water flow in forested environments.

In general, the more elevation and slope in a region the more organized and efficient the drainage network and the greater the surface water flow. Topography has a greater influence on wetland development in boreal regions with shallow soils and impermeable bedrock (e.g. boreal shield ecozone), but less of an influence in regions with greater water storage capacity due to deep soil deposits and permeable bedrock (e.g., boreal and taiga plains ecozones; Devito et al. 2012; Gingras et al. 2016).

Much of the commercial forestry in western Canada is in the Boreal and Taiga Plains ecozones which are regions without exposed impermeable bedrock and with deep soil deposits ranging from well drained sands and gravels to poorly-drained fine silts and clays. Terrain in these areas may be flat to gently undulating to hummocky. In general, wetlands have formed in areas with flat terrain and poorly drained soils and have developed into expansive and interconnected complexes with complicated hydrology. In the Taiga and Boreal Cordillera of Alberta and B.C., wetlands have typically formed in plateaus and valleys in locations with flatter topography and poor soil drainage and are often along or associated with riverine systems (Warner 2004; Gingras et al. 2016).

Depending on the local climate, geology, and topography, water within a wetland may move vertically, laterally, or a combination of both (Partington et al. 2016). Wetlands can be grouped to reflect similar flow (hydrologic) characteristics. These groupings can be used to predict expected surface and subsurface water flows and fluctuations. When planning forest management activities knowing the wetland class provides insight into predicted flow characteristics. Flow groupings are described in (Table 1) for wetlands under average climatic conditions, these groupings are expected to be influenced by the timing and magnitude of precipitation events.

Table 1: Wetland hydrological groupings and their features. Groupings are appropriate during average climatic conditions. All boreal wetland types are likely to be connected under high precipitation conditions and flow in most wetland types is likely to be affected by the amount of precipitation, more rain leading to increased flow. Under dry conditions, connectivity and flow rates are likely to be lower.

Hydrologic Group	Water source	Hydrologic connections	Soils	Wetland types	Other
Stagnant	Precipitation	May be isolated with water at or below the surface; however, stagnant wetlands are often connected to adjacent wetlands and uplands. Stagnant wetlands are not completely without movement (e.g., serve as sources following high precipitation events)	Deep organic layers	Treed bog, shrubby bog, open bog, conifer swamp, and treed poor fens	Unlikely to be near a defined peat channel little discernable water movement
Slow Lateral-Flow	Precipitation, runoff and groundwater	Typically connected to adjacent wetlands with slow water movement at or below the surface	Deep organic layers	Treed rich fen, shrubby rich fen, graminoid rich fen, shrubby poor fen, and graminoid poor fen	Less likely to freeze because of surface and subsurface water movements year round
Seasonally Fluctuating	Precipitation, runoff and groundwater	Often part of a flowing system with slow water movements at or below the surface and periodic lowering of the water table	Typically woody organic layers over mineral soils	Mixedwood swamp, hardwood swamp, shrub swamp, and tamarack swamp	May be obvious water movement
Inundated/ Flooded	Precipitation, runoff and groundwater	Can be isolated or connected to flowing systems with seasonal or annual water fluctuations	Mineral soils	Emergent marsh, meadow marsh, open water, and aquatic bed	Often transitional zone between deep lakes and adjacent swamps or uplands

While flow groupings provide important information about water movement, how a specific wetland is affected by a disturbance (e.g., a road) depends on additional factors including surficial geology. Surficial geology may be a more significant driver for some wetland types than for others. For example, bogs underlain with fine textured material show a greater ecological response (reduced canopy cover upstream, increased canopy cover downstream) at road crossings compared to bogs underlain with coarse material (Willier 2017). In contrast, Willier (2017) found that surficial geology was a less important driver in rich and poor fens intersected by roads. This means that while wetland types grouped as 'stagnant' are often at lower risk of hydrologic impairment due to typically slower flow rates, they are not without risk. The potential for water movement needs to be considered for all wetland types.

Benefits of Wetlands

In the past, wetlands have been referred to as unproductive in terms of forest management and sometimes passive or even undesirable areas of the landbase. Wetlands are often not included in as part of the 'active' landbase managed by forest companies. However, they are often still considered at various points such as when planning access to harvest blocks. In parts of Canada, such as Ontario's claybelt, wetlands may be drained in the hopes of "improving wetlands for forestry" (e.g. Hillman 1987). In parts of western Canada, conifer swamps may be harvested depending on whether trees are merchantable and site characteristics. Boreal wetlands provide many important ecological, social, and economic services and commodities that directly and indirectly benefit humans (Gingras et al. 2016). For example, Anielski and Wilson (2009) estimated the non-market economic value provided by boreal wetland ecosystems to be ~$5.12 billion / year. These benefits include: regulating, provisioning, cultural, and supporting ecosystem services (Millennium Ecosystem Assessment 2005). Recent work by the International Union of Forest Research Organizations has shown that forests, and particularly natural forests, contribute to the resilience of water supply for humans in the face of changing climate and ecosystems (IUFRO 2018). Further, the report recognizes that forests can be managed to contribute to the resilience of water supplies and systems.

Regulating services

Regional and global climate

Wetland abundance and diversity can influence local, regional and global climate patterns by influencing rainfall, temperature, and greenhouse gas exchanges. At the local scale, research has shown that in regions where wetlands compose a large portion of the landscape their moist surface can help maintain regional evapotranspiration, even during dry periods (Rouse et al. 2003; Van der Kamp and Marsh 2013). Globally, wetlands, specifically peatlands, represent a major storehouse of soil carbon and an ongoing sink for carbon dioxide. In fact, more carbon is captured and stored in Canada's peatlands than by trees in forests (*e.g.*, Henschel and Gray 2007).

At the same time, peatlands can be a significant source of methane emissions and the current balance between carbon storage, carbon sequestration, and methane emissions can be altered by climate change or land use changes. For example, peatland drying due to drought or linear

> ***Melting permafrost***
>
> Peatlands underlain with permafrost may sequester more carbon as permafrost melts and the wetland transitions to wetter fen classes with increased plant growth. However, these changes could potentially result in elevated methane emissions due to low oxygen availability.

infrastructure may result in increased burning during fire events, in turn releasing stored carbon into the atmosphere (International Peat Society, 2008).

Hydrology

Boreal wetlands regulate local and regional hydrologic regimes, including storing and moving surface and ground water. In particular, peatlands store and/ or release large amounts of water helping maintain water flow during droughts and floods.

Depending on the climatic cycle (e.g. whether a dry or wet year) wetlands can be water sources or water sinks. During dry events, the water retention properties of all wetlands can help regulate water flow during storm-water peak events and may help to control erosion.

Recent studies (e.g., Hillman and Rothwell 2016, Donnelly et al. 2016, McEachern 2016, Devito et al. 2017), demonstrate the important role wetlands play in regulating watershed hydrology and buffering potential increases in run off due to timber harvesting.

Provisioning services

Provisioning services are those benefits from a wetland that supply a good or product to society (Millennium Ecosystem Assessment 2005). Boreal wetlands provide a number of provisioning services including:

- supplying fresh water
- replenishing ground water sources important for domestic and industrial use
- providing wild game & foods
- wood fuel and commercial wood fibre
- supporting fur-bearer resource for trappers

Other provisioning services include providing habitat for economically important pollinators and for medicinal plants (Gingras et al. 2016).

Cultural services

Boreal wetlands and associated riparian habitats provide a variety of cultural ecosystem services (see Gingras et al. 2016 for a detailed summary). For thousands of years, wetlands have been important to Indigenous Peoples, providing reliable travel corridors, important areas for hunting game, and harvestable goods used for food, shelter, and medicine. Today, wetlands remain an integral part of indigenous culture.

Canadians from all backgrounds may derive spiritual, inspirational, or recreational benefits from boreal wetlands including canoeing, hunting, hiking, fishing, trapping and birdwatching (Gingras et al. 2016).

Wetlands make great outdoor classrooms for all ages. Students can learn about wetland ecology and the ecosystem services they provide.

Supporting services

Boreal wetlands provide habitat for hundreds of species of plants and animals and are important areas for biodiversity conservation. In addition to species level benefits, biodiversity can indirectly influence ecosystem function and resilience (Elmqvist et al. 2003).

For North American waterfowl populations, the boreal forest and the prairie pothole regions are the two most important landscapes for breeding waterfowl (Ducks Unlimited Inc. 2005). An estimated 26 million waterfowl utilize boreal wetlands as migratory stop overs or as breeding habitat each year (Gingras et al. 2016).

Wetlands, within identified caribou ranges, are also important to boreal woodland caribou, a federally listed threatened species, as areas for travel, feeding, calving and avoiding predators. As well many plants and animals are wetland specialists (e.g., bog pitcher plant) and rely exclusively on wetland habitats while other species (e.g., boreal woodland caribou) utilize wetlands for significant portions of their life cycle (Gingras et al. 2016; Smith et al. 2007b).

Economic valuation of wetland services

Few provisioning services have a measurable market value that is tracked which makes it difficult to place a dollar value on these services. That said, several reports provide reliable estimates. Wild rice, for example, is primarily produced in Manitoba, Saskatchewan, and Ontario's wetlands with industry estimated exports at $5 million worldwide in 2012 (Government of Canada 2016). Anielski and Wilson (2009) provide preliminary estimates of wetland ecosystem services in terms of non-market value estimating:

1. Annual value of carbon storage of wetlands (including peatlands) at $400 billion
2. Replacement cost value of sequestered carbon in peatlands at $383 million
3. Value of flood control, water filtration and biodiversity in mineral soil wetlands at $34 billion and peatlands at $77 billion

> While not common in western Canada, timber harvesting on swamps is common in northern Ontario and Quebec; specifically, harvesting black spruce in conifer swamps and bogs with 0.5 to 1.5 m peat depth (Locky 2009). Black spruce fibre is highly valued for certain types of pulp production (Alberta Wood Products 2017) and in Alberta, black spruce accounts for 15% (~130million m^3) of the Province's forest inventory (Forintek Canada Corp. 2006).

Chapter Two Summary

- While there is no single, legally recognized, wetland definition that is applicable across all municipal, provincial, and federal jurisdictions in Canada there are three key features that define a wetland:
    - Poorly drained soils
    - Hydrophytic vegetation
    - Biological activity adapted to a wet environment
- Wetlands vary in size and complexity from small local features to large complexes. The diversity of moisture regime and vegetation present can sometimes pose challenges for differentiating between wetlands and uplands.
- The variety of ecological functions can be grouped into four main categories: hydrology, biogeochemical cycling, climate regulation, and habitat.
- Wetlands can be categorized as organic or mineral based on soil type and depth of organic deposits. Wetlands can be further broken down into five major wetland classes: bogs, fens, swamps, marshes, and shallow open water, each with their own defining characteristics.
- Wetlands can be grouped to reflect similar flow characteristics, these groupings can be used to predict expected surface and subsurface water flows and fluctuations under average climactic conditions. High and low precipitation events or cycles can alter these expected flow characteristics.
- Wetlands provide many important ecosystem services including regulating, provisioning, supporting, and cultural services. For example, wetlands can help regulate regional and global climate while also serving as important areas for recreational boating and bird watching.

Chapter Three: Wetland and Forest Management Interactions

Wetlands are an integral component of boreal forest ecosystems and intersect in a number of ways with forest management activities. Understanding how wetlands and forest management intersect and the associated benefits and challenges can help forest managers address wetland stewardship objectives. In this Chapter we will discuss the benefits and challenges associated with conducting forest management activities in a wetland rich landscape, including:

1. benefits of wetlands to upland forests and forest management
2. challenges of conducting forest management activities in and around wetlands
3. potential adverse effects of forest management activities on wetlands
4. role of sustainable forest management in supporting wetland stewardship

The benefits and challenges discussed in this Chapter will be referenced throughout the rest of the document and will provide the background to the Stewardship Objectives identified in Chapter Five and Planning Considerations discussed in Chapter Six.

Benefits of wetlands to upland forests and forest management

Wetlands can provide benefits to adjacent and nearby upland forests, which in turn can benefit forest management. Benefits include: (1) contributing to forest productivity and resiliency; (2) mitigating the effects of upland harvest on waterbodies; (3) providing protective measures against wildfires, and; (4) mitigating anticipated effects of climate change.

Contributing to forest productivity and resiliency

While wetlands and uplands may be considered differently in forest management planning and operations, they are often hydrologically connected with water re-distribution occurring through groundwater or through lateral surface or near surface run-off (Devito et al. 2012; Devito et al. 2016).

- During drought cycles and dry periods, wetlands in the Boreal Plains ecozone store and redistribute water to the landscape.
- During wet cycles or periods, wetlands in the Boreal Plains are capable of transmitting large amounts of water through the landscape, potentially mitigating flood events.
- Upland forests and open water bodies act as sinks while various vegetated wetlands with little or no standing water act as sources that can contribute to increased forest productivity in upland habitats that may otherwise face water deficits (Thompson et al. 2015).

Wetlands as a source of water for regenerating upland forest stands:

For regenerating forests stands, wetlands can provide additional water sources and influence vegetation cover, growth and yield recovery (Donnelly et al. 2016).

Following harvest, regenerating aspen stands may use water resources from adjacent wetlands by suckering from forestlands through riparian zones to wetlands (Petrone et al. 2016).

Figure 11**.** Aspen root suckers connecting to adjacent wetland (photo credit Kevin Devito)

Mitigating the effects of upland harvest

Runoff from roads and harvested areas can result in erosion and sedimentation into wetlands and waterbodies. Wetlands can play an important role in mitigating the effects of forest harvest on water yield and water quality by reducing runoff and contribute positively to recovery as documented in the Forest Watershed and Riparian Disturbance Project (FORWARD) in west central Alberta (McEachern 2016). However, this mitigating role may be dependent on climatic conditions.

- Under normal dry conditions, when water tables are lower and peatlands are below storage capacity, they are able to absorb inputs from precipitation (Prepas et al. 2006; Hillman and Rothwell 2016).
- Under wet conditions, when water tables are high and peatlands are at storage capacity, water is released from wetlands as runoff (Prepas et al. 2006; Hillman and Rothwell 2016).
- Wetlands may act as water source areas that generate most of the stream flow (Donnelly et al. 2016).

Protecting against wildfires

Wildfires are one of the largest disturbances affecting the boreal forest and can pose a risk to forest resources and management activities. Although wildfire can affect wetlands, wetlands can also help mitigate the effects of forest fires on adjacent uplands and assist with regeneration following disturbance.

- Hydrological feedbacks inherent to peatlands (e.g., feedback processes associated with moss growth and peat formation or shading and evaporation) are believed to be important for controlling vulnerability to wildfires (Waddington et al. 2015; Johnstone et al. 2010).
- Hydrological feedbacks coupled with: thick wet soils, low evapotranspiration (particularly in black spruce wetlands), and water retention by mosses limit wildfire frequency and inhibit deep burning under most fire weather conditions (Schiks et al. 2016; Johnstone et al. 2010).

- Wetlands may also contribute to vegetation regeneration in connected uplands by transmitting water across the landscape.
- Open water wetlands can also serve as water sources for fighting fires.

Mitigating effects of climate change

The same mechanisms that help peatlands control vulnerability to wildfires (i.e. hydrological feedbacks, wet soils, low evapotranspiration, high water retention), can also play an important role in peatland response to climate change (Waddington et al. 2015). By reviewing the processes that will mediate ecological responses to projected changes in climate, Schneider et al. (2016) found that if precipitation inputs are maintained as expected, boreal peatlands should exhibit considerable resilience to climate change. Peatland persistence and capacity to retain water in a changing climate may benefit upland, and particularly aspen, by supplying these forests with water resources (Schneider et al. 2016).

Challenges of conducting forest industry activities in and around wetlands

If wetlands are not identified and planned for, they can pose some challenges to forest industry activities including: (1) additional considerations, time and cost when planning, building, and maintaining resource roads; (2) worker and equipment safety, and; (3) ensuring compliance with legal and certification requirements while obtaining and maintaining the social license to operate.

Resource roads

Working in or near wetlands can be challenging because of the presence of surface or sub-surface water, saturated soils, and deep peat deposits. Although many wetlands are not suitable for harvest, their prominence throughout the boreal landscape will, in many cases, necessitate crossing to access harvest blocks. Constructing roads through wetlands without understanding and planning for their flow characteristics can lead to:

- flooding
- freeze down challenges
- rutting
- damaged culverts (e.g., sunken, bent)

Understanding wetland hydrological and ecological characteristics can help inform the route, road design, and timing to navigate to avoid and minimize negative effects to wetlands. For more information refer to Chapter Six.

Constructing wetland crossings without an understanding of anticipated flows can delay access to areas of operation at certain times of the year (e.g., flooding in the spring), can create safety issues (e.g. flooding and icing of roads during winter) and increase road maintenance costs. However, planning for activities through wetlands can also be costly. Roads that fail to maintain natural wetland hydrology can also have ecological consequences. Flooding upstream of the road generally results in vegetation die back (i.e. of trees and shrubs) and a shift to more water tolerant vegetation, while drying out downstream results in more vigorous vegetation growth. Willier (2017) recorded this phenomenon across a range of peatland types in northern Alberta. Linear disturbances, such as roads, may increase predation of certain species (directly or indirectly), influencing wetland function from a biodiversity perspective (e.g., McCutchen 2007; McKenzie et al. 2012).

Building roads through different wetland types may require additional preparation of the road bed with a variety of measures to handle drainage (e.g., additional culverts, geotextiles, Partington et al. 2016).

Figure 12. Example of wetland road challenges clockwise from top left: perched culvert, sunken culvert, blocked flow, and road compaction.

Safety

Wetlands, particularly those with deep peat and flowing water, can pose safety challenges to worker and equipment operating in these locations. Safety concerns are increased in the shoulder season or during mild winters when ice roads may develop weak spots but are present year-round regardless of temperature.

> ***Understanding wetland type is important for worker and equipment safety***
>
> Areas with flowing subsurface water movement, as is often found in fens, can require additional work to freeze down. Further, these areas can add to safety concerns for workers operating equipment, and can make retrieving equipment more challenging, time consuming, and expensive (e.g., Grayson 2016).

Figure 13. Example of equipment submerged in a peatland. Understanding wetland type can provide information about potential peat depth and subsurface water flow, important considerations for making safe decisions when operating in and around wetlands. Photo credit Millar Western Forest Products Ltd.

Legal, certification, and social license

Wetlands are receiving increasing attention in legal, policy and certification requirements and meeting these requirements can pose challenges for forest managers. The federal wetland policy (Government of Canada 1991) provides over-arching guidance on wetland conservation in Canada but is limited to federal land. As a result, conserving and managing wetlands on private, provincial and territorial land has been largely left to provinces and territories to lead and enforce. Legislation relevant to forest management activities and wetlands varies by province and territory; understanding responsibilities under the relevant legislation can help with planning operations to minimize potential legal challenges.

Wetland policy across Canada

Five provinces have provincial wetland policies: Alberta, Prince-Edward Island, Nova Scotia, Newfoundland and Labrador and New Brunswick and other provinces and territories are exploring or have committed to developing wetland policies (e.g., Ontario, Yukon, Manitoba).

Canadian forest certification programs are increasingly recognizing wetlands in their standards. Depending on current company practices these requirements do not necessarily pose a challenge to forest managers, but they may require additional consideration or reporting when working in or around wetlands.

Finally, water resources, including wetlands, are receiving increasing attention from a wide range of stakeholders. Ensuring that wetlands are sustainably managed is an important component of obtaining and maintaining social license to operate in the Canada's boreal forest.

Potential effects of forest industry activities on wetlands

Forest industry activities have a range of potential negative effects on wetlands depending on the activity, approach, time of year, wetland type, and meteorological conditions. Potential direct and indirect effects on wetlands can include: (1) changes to wetland hydrology; (2) wetland loss; and (3) changes to wetland quality. Damage to wetland quality, quantity, and hydrology could reduce the capacity of the wetland to provide important ecological goods and services.

A note on harvesting in treed wetlands: Treed wetlands are not typically targeted for harvesting in Canada's Boreal Plains ecozone. However, due to the difficulty of identifying some treed wetland types as wetlands (i.e. conifer swamps) some harvesting of these habitat types does occur. In areas where wetlands are harvested, regeneration can lead to a shift towards upland forest, resulting in wetland loss. Harvesting can alter the hydrology not only of the harvested area, but also of connected wetlands and uplands. Harvesting can potentially affect the water table level and lead to runoff or increased groundwater recharge depending on topography, soil and surficial geology. Harvesting in treed wetlands will not be addressed in further detail in this document, but additional considerations are required if wetlands are to be harvested.

Wetland hydrology

Forest industry activities have the potential to alter wetland hydrology including flow within a wetland, between wetlands, and between uplands and wetlands. Common forest management activities such as building and maintaining resource roads, skidding or transporting felled timber within a harvest block, landing sites, camps, and equipment storage have the potential to disrupt the natural hydrology. Changes to hydrology can result in loss of connectivity and hydrologic networks and changes to biological communities.

Wetland loss

Wetlands are typically avoided during harvesting as they are often viewed as 'unproductive' areas from a timber perspective. However, they are often crossed to gain access to harvest areas and they may be used for landings. Wetland loss can occur if sites are impaired the point of impeding vegetation regeneration and sending site recovery on an alternate (upland) path (Lavoie et al. 2005; Locky and Bayley 2007; Roy 2000a; Roy 2000b; Sheehy 1993).

Petrone et al. (2006) found that harvesting in adjacent forested areas may inadvertently enhance evaporative losses from wetlands. For small wetlands, these changes could potentially result in wetland loss due to drying conditions. If small sub-canopy pools (*e.g.* vernal pools) are not captured by inventory, but which contribute to forest biodiversity, are inadvertently missed and potentially impacted during forest operations.

Wetland quality

Soil

Wetland soils are wet, loose, and have weak bearing capacity, making them especially prone to rutting, erosion, and compaction particularly during frost free periods (AAFC 2007, Nugent et al. 2003). Soil compaction and soil disturbance can occur if roads are built across wetlands. If skid trails or landings are in or near wetlands, heavy equipment can cause soil compaction, rutting and ponding of water. Soil rutting and compaction can:

- impede plant establishment and development including impeding root growth, air infiltration, emergence, and access to water and nutrients (Whiting et al. 2014; AAFC 2007)
- damage existing vegetation and their root systems (Lantagne et al. 1998)
- lead to stunted growth from nutrient and water deficiencies, and badly formed roots from an inability to properly penetrate the soil (Kozlowski 1999; DeJong Hughes et al. 2001)

Figure 14. Example of soil rutting and compaction

Water quality

Forest management activities taking place in or near wetlands can result in erosion and sedimentation, mechanical leaks and spills (e.g., oil, gas, other fuels), and vegetation management inputs (e.g., herbicides), all of which can alter water quality. Activities that expose soils including roads, trails or harvesting may cause erosion with soil being transported into wetland surface water if steps are not taken to prevent erosion. Sedimentation can:

- alter plant community structure by reducing seedling establishment or suffocate growth
- affect aquatic invertebrates, fish and amphibians by burying bottom dwelling organisms and eggs
- lower community biomass, diversity, and richness (Mahaney et al. 2005; Gleason et al. 2003)

Increased turbidity levels from suspended sediment can reduce light penetration, increase water temperatures, reduce plant growth, and reduce visibility for fish and other predatory species. Other potential pollutants such as fuels and herbicides can directly (kill) or indirectly (e.g., reduce growth, lower life expectancy, reduce reproductive success) affect wetland animal and plant life.

Vegetation

Wetland vegetation acts as a filtration system, stabilizes soil, and creates habitat for a variety of wetland dependent species. Disturbing wetland vegetation can result in the loss or alteration of these ecosystem services. Removing wetland vegetation can expose soil to erosion and sedimentation which can decrease water filtration capacity. Disturbing vegetation can also alter or remove rare ecological communities and rare plant habitats.

Invasive species

The introduction and spread of invasive species has the potential to affect wetland quality. Outside of their native habitat, these species may have no natural controls and may replace valuable native species. Incoming unmonitored vehicles may facilitate the spread of invasive species if equipment is not properly cleaned when moving among sites. Invasive species could be carried in by equipment, vehicles and crews (forestry or other industries using the same transport corridors), recreational vehicles, or boats. Recreational vehicle users tend to be more challenging to monitor and enforce than industry vehicles and equipment and can thus pose additional challenges.

Benefits of sustainable forest management to wetland stewardship

Managing timber harvest sustainably is complementary to sustainable wetland management. In Canada, the forest industry has demonstrated a commitment to Sustainable Forest Management (SFM) and Ecosystem Based Management (EBM) that embraces a balance between ecological, economic and social values. Wetlands are an important ecosystem component that contribute positively to healthy upland forests. To effectively implement EBM, forest managers need to consider all the components of a healthy functioning forest ecosystem during their forest planning, operations, and renewal. These components include:

> **Ecosystem Based Management** (EBM) means taking a holistic view of environmental management, when applied EBM can help support the long-term health of forest systems and the wetlands within.

- landscape and local biodiversity - ecosystem, species, and genetic diversity
- water quantity and quality

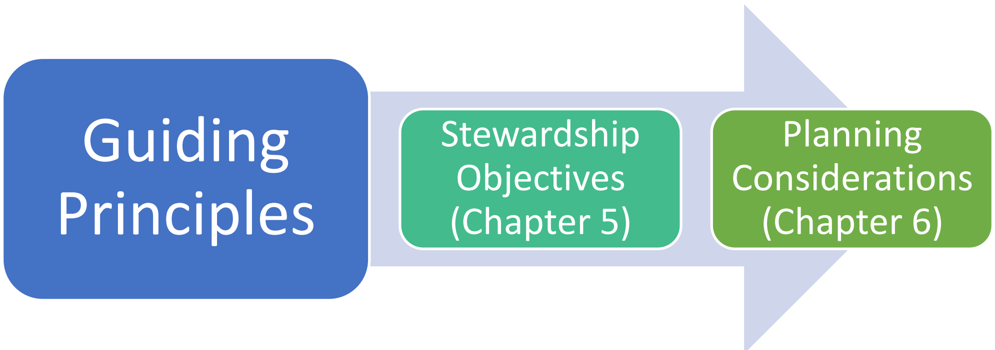
- soil productivity
- local, regional and global climate and nutrient cycling

Canadian forest managers are responsible for managing, often large tracts of, public land in a way that ensures the long-term productivity and sustainability of the land base. This long-term investment in sustainable development means that forest managers must work with other stakeholders (*e.g.*, public, Indigenous peoples, other industries) to maintain healthy systems and achieve multiple objectives. Forest managers can influence behavior within their companies, and externally, to promote wetland stewardship through implementing best management practices (BMPs) to support the guiding principles described in this report.

Chapter Three Summary

- There is increasing evidence that boreal wetlands contribute to forest productivity and resiliency. Peatlands in particular serve as water sources and are capable of transmitting large amounts of water through the landscape.
- Wetlands may mitigate the effect of upland harvest on waterbodies, help to protect against wildfires, and mitigate effects of climate change.
- Wetlands can pose challenges to forest managers including: additional considerations, time and cost when planning, building and maintaining resource roads; worker and equipment safety; and ensuring compliance with legal and certification requirements.
- Forest management activities can affect wetlands including potential changes to wetland hydrology, quantity, and quality (e.g., soil properties, water quality, vegetation, and invasive species).
- Canadian forest managers are responsible for managing public land in a way that ensures the long term productivity and sustainability of the land base. To accomplish this, forest managers must work with other stakeholders (e.g., government, public, Indigenous Peoples, other industries). Forest managers can influence behavior within their companies and externally, to promote wetland stewardship through implementing best management practices (BMPs) to support the guiding principles described in this report.

Chapter Four: Wetland Stewardship Principles



Wetlands provide a range of functions and values that are important to maintain in forested systems. In addition to benefitting forests and forest management as discussed in Chapter Three, wetlands provide many ecosystem goods and services including the regulating, provisioning, supporting, and cultural services as discussed in Chapter Two. However, wetlands can also pose challenges to forest management activities and some forest management practices may negatively affect wetlands. This Chapter describes four wetland stewardship principles that outline the key environmental outcomes that need to be achieved to conserve wetland resources on the landscape:

1. maintain wetland quantity
2. maintain wetland quality
3. maintain hydrologic processes
4. maintain hydrologic connectivity

Stewardship Objectives for meeting these Principles will be discussed in Chapter Five and suggested Planning Considerations for meeting these objectives will be discussed in Chapter Six. These four principles are intended to serve as overarching guidance that will help forest managers meet other related objectives. Working to achieve these principles will support other related values identified under government or certification requirements (e.g., refer to Table 2). For example, by maintaining wetland quantity, quality, hydrologic processes and hydrologic connectivity, we expect to maintain biodiversity of plants and animals that use these habitats. A similar set of seven hydrological principles for conservation of water resources in forested landscapes was introduced by Creed et al. (2011); however, the four principles in this document focus on wetland conservation.

Table 2. The wetland Guiding Principles identified in this chapter can help support values from the Alberta Forest Management Planning Standard (2006) and objectives from the SFI Forest Management Standard (2015-2019).

Alberta Forest Management Planning Standard 2006	SFI 2015-2019 Forest Management Standard requirements
Landscape scale biodiversity	Forest management planning
Local stand/ scale biodiversity	Forest health and productivity
Viable populations of identified plant and animal species	Protection and maintenance of water resources
Effective riparian habitats	Conservation of biological diversity
Water quantity	Management of visual quality and recreational benefits
Soil productivity	Protection of special sites
Control invasive species	Legal and regulatory compliance
Compliance with government regulations and policies	Public land management responsibilities
Areas with minimal human disturbances within managed landscapes	Training and education
Sustainable timber supply	
Forest productivity	
Ecosystem resilience	

Maintain wetland quantity

Where feasible, avoiding wetlands is the best approach to maintaining wetland quantity. Avoidance is typically at the top of policy, regulatory and voluntary wetland mitigation hierarchies (see Chapter Six for additional information on avoidance). Wetland loss results in the removal or loss of function (i.e. degradation of ecosystem goods and services). Because wetlands in Canada's boreal are often highly connected, and the extent and nature of these connections are often poorly understood, wetland loss can have unanticipated consequences on how water moves across the landscape. Depending on the extent, wetland loss can result in (Wetlands Alberta 2017):

- loss of habitat
- loss of plant and animal diversity or shifts in dominance
- degraded water quality
- reduced productivity in connected upland forests
- changed hydraulic regimes
- reduced water supply and potentially water shortages
- loss of flood plain land and flood plain protection
- reduced recreational opportunities
- loss of aesthetic values
- reduced groundwater recharge
- increased risk of wildfire (Thomson 2016)

Because wetlands play an important role in distributing water across the landscape, wetland loss can indirectly affect other parts of the landscape including upland areas targeted for harvest. Wetland loss can affect carbon storage and sequestration capacity and increase the release of greenhouse gases (e.g., Roulet and Moore 1995, Fenner and Freeman 2011), particularly in boreal peatlands where deep peat deposits hold an estimated 59% of Canada's soil carbon (Bauer et al. 2005).

Maintain wetland quality

Maintaining water quality is critically important to supporting healthy wetland ecosystems. Alterations to water quality including the introduction of pollutants, additional sediment, or additional nutrients can compromise water quality and influence species composition including vegetation and other wetland biota. Peatland water quality has also been shown to influence water quality of surrounding areas (Ferone and Devito 2004; Creed et al. 2008; Mertens 2018). Halsey et al. (1997) found that the extent and type of peatlands in watersheds plays an important role in determining the pH status of lakes, suggesting that alterations to peatlands has the potential to have further reaching effects. Mertens (2018) found that factors such as permafrost, thickness of overburden, and topographic position play a role in nutrient distribution, but that peatland abundance has an important relationship with nutrient distribution.

Changes to water quality can include shifts in salinity, pH, electrical conductivity, and major ions (e.g., CA^{2+}, Mg^{2+}, Na^{+}, CL^{-}, SO_4^{2-}, HCO_3^{-})

Maintaining soil integrity and quality is also key to maintaining wetland quality. As discussed in Chapter Two, wetland soils, and particularly saturated and organic soils, are sensitive to disturbances. Wetland soils are the medium for many of the chemical transformations that take place in wetlands as well as the primary chemical storage location for most wetland plants (Mitsch and Gosselink 2015). Activities in wetlands can affect soil:

- bulk density and porosity
- hydraulic conductivity, nutrient availability
- cation exchange capacity

These alterations are tied to the hydrologic regime and can affect vegetation growth and the presence of other biota.

Maintaining wetland biogeochemistry is about maintaining the natural transport and transformation of chemicals in wetlands. Both hydrology and soil type strongly influence biogeochemical processes, including chemical forms and spatial movement of materials within a system and between a wetland, surrounding water, landscapes and atmospheres. Important wetland biogeochemical processes include:

- the nitrogen cycle
- iron and manganese transformations
- the sulfur cycle
- the phosphorus cycle

Alterations to wetland water quality, soil integrity, and biogeochemistry can ultimately lead to changes in wetland structure and function. Given the variety of ecological goods and services provided by wetlands, it is important to identify potential adverse effects and apply practices to avoid and minimize adverse effects to wetland quality.

Maintain hydrologic processes

Wetland hydrology is the most important determinant of a wetland's structure and function. Wetland hydrology is determined by climate and basin geomorphology and refers to changes to things such as water level, flow, frequency of flow, etc. which can modify a wetland's physiochemical environment including nutrient availability, oxygen availability, pH, and toxicity (Mitsch and Gosselink 2015). Avoiding potential changes to hydrologic processes is critical to maintaining wetland structure and function.

> Hydrologic processes are what makes a wetland a wetland, and changes to these processes may result in a shift in wetland type, but can also result in a shift from wetland to upland

The main wetland hydrologic processes that can be affected by forest management activities and that should be maintained include:

- the hydroperiod (seasonal pattern of flooding duration and frequency and water depth)
- water budgets (changes in water volume from precipitation, streamflow, groundwater)
- water storage potential (Devito and Mendoza 2006)

These processes are responsible for the transport of sediments, nutrients, species (e.g., plant, fish, amphibian), and toxic substances into and out of wetlands. Alterations, either natural or as a result of disturbance, can significantly influence the vegetation, microbe, and other biota species composition.

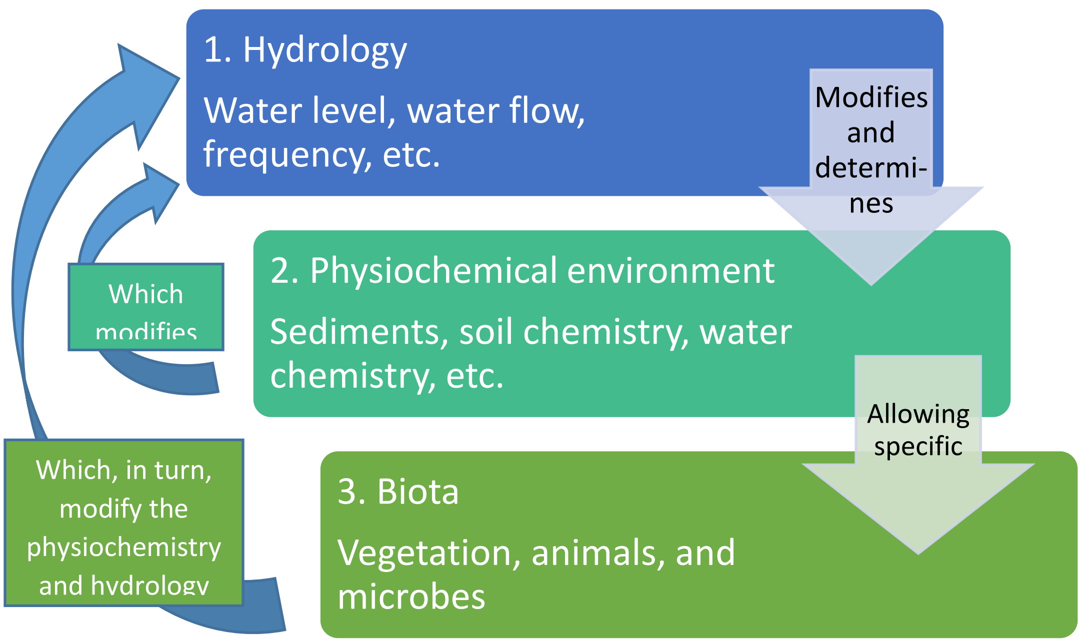


Figure 15. Conceptual diagram of the relationships between wetland hydrology, physiochemical environment, and biota. Demonstrates the effects of hydrology on wetland function and the feedbacks that can affect wetland hydrology.

More specifically, hydrology has four important effects on wetland function, these include influencing:

- vegetation composition
- primary productivity and other ecosystem functions

- accumulation of organic material
- nutrient cycling and availability (Mitsch and Gosselink 2015)

Changes to hydrologic processes such as the flow-through rate can increase or decrease vegetation species richness and primary productivity. For example, peatlands with flow-through conditions such as fens are more productive and have greater species richness compared to isolated bogs. It is expected that an alteration leading to decreased flow-through would result in decreased productivity and potentially other consequences such as carbon storage.

Maintain regional hydrologic connectivity

Wetland hydrologic connectivity refers to how surface, shallow sub-surface and ground water are connected to surrounding areas. These connections may not be obvious, nor are they often well understood, but alterations to hydrologic connectivity can have significant adverse effects that may not be immediately apparent (Pringle 2003). Because of a lack of data about hydrologic connectivity, it is often overlooked until water quality or quantity issues arise (Pringle 2001).

Hydrologic connectivity is '*the water mediated transfer of matter, energy, and/ or organisms within or between elements of the hydrologic cycle*' Pringle 2001.

Because hydrologic connectivity plays an important role in transporting matter, energy and/ or organisms, maintaining regional connectivity is an important wetland stewardship principle for forest managers. Blocking flow can alter water chemistry and ecological communities by impeding water inflow and the accompanying transport of organic material and nutrients. In boreal wetlands, hydrologic isolation by a linear feature can result in upstream flooding and downstream drying. Over time, this change to how wetlands are connected can cause a shift in vegetation communities with increased productivity downstream and decreased productivity upstream.

Wetlands are important features at the landscape level and are responsible for storing and transmitting water across the landscape. For peatlands, their main contribution is horizontal flow either at the surface or through the upper layers of peat (Rydin and Jeglum 2006). The ability of wetlands to transmit water varies by wetland type and seasonal conditions. For example:

- fens tend to be more hydrologically connected to the overall drainage system compared to bogs that may only transmit under very wet conditions (Quinton et al. 2003)
- connectivity in northern peatlands tends to be highest in the spring when spring thaw is transmitted quickly across frozen ground, and lowest in the summer when wetlands become hydrologically isolated as they dry out (Rydin and Jeglum 2006)

Depending on the position of the wetland within the watershed and whether it is isolated or connected, blockage of flow could directly affect a specific wetland or could have implications for hydrologic connectivity at the regional or landscape scale(s).

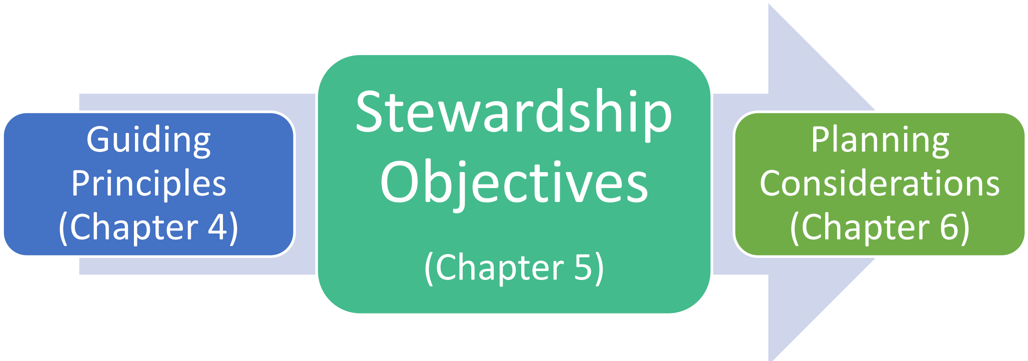
Maintain a diversity of wetland types

Some wetland types may be more abundant on an FMA and some forest industry activities may be more likely to affect certain wetland types. If wetlands (quantity, quality, processes or connectivity) are affected by activities, understanding the location and relative abundance of wetland types at local, regional and landscape scales and considering wetland function, ecosystem services, and rarity will help forest managers plan to maintain the diversity of wetland types and services these wetlands provide. Different wetland types provide different ecosystem goods and services. For example, peatlands store and sequester large amounts of carbon while shallow open water wetlands can be very productive for waterfowl. Maintaining a diversity of wetland types can help ensure that the full suite of goods and services continue to be provided.

Chapter Four Summary

- In this Chapter we identified four guiding principles that if addressed will support wetland stewardship. Principles are: maintain wetland quantity; maintain wetland quality; maintain hydrologic processes; and maintain hydrologic connectivity.
- Working towards these guiding principles can help support other related values identified as part of government and/ or certification such as value identified as part of the Alberta Forest Management Planning Standard (2006).
- Maintaining wetland quantity requires avoiding wetland loss and will help maintain the values and functions wetlands provide. Maintaining redundancy and diversity of wetland types will help maintain the full suite of values different wetland types provide.
- Maintaining wetland quality requires maintaining water quality, soil integrity and quality, and wetland biogeochemistry.
- Wetland hydrology is the most important determinant of a wetland’s structure and function. Ensuring that potential adverse effects to hydrologic processes are avoided where feasible and otherwise minimized is critical to maintaining wetland structure and function including: vegetation composition, primary productivity, accumulation of organic material, and nutrient cycling and availability.
- Boreal wetlands are rarely isolated systems and maintaining regional hydrologic connectivity (surface, shallow sub-surface, and ground water connections) is important for maintaining individual wetlands, the wetland complexes they are a part of, and the productivity of the uplands they support.

Chapter Five: Wetland Stewardship Objectives



As discussed in Chapter Four, the key environmental outcomes that need to be achieved to conserve wetland resources on the landscape are maintaining wetland quantity, wetland quality, key wetland hydrologic features or processes, and regional hydrologic connectivity. The wetland stewardship objectives discussed in this chapter are general approaches to help achieve these outcomes.

The objectives were developed by grouping potential adverse effects of forest management activities on wetlands and should be considered during all stages of forest management including planning, operations, renewal, and for infrastructure such as roads - decommissioning. Meeting the objectives will demonstrate wetland stewardship and help achieve the key wetland environmental outcomes identified in Chapter Four. Wetland stewardship objectives discussed in this chapter are listed in Table 3 alongside the Guiding Principles they support.

Table 3. Relationships between Guiding Principles described in Chapter Four and Stewardship Objectives described in this chapter.

Objectives	Guiding Principle(s) the objective supports
Maintain wetland surface and subsurface water flow	Maintain wetland quantity Maintain wetland quality Maintain wetland hydrologic processes Maintain regional hydrologic connectivity
Avoid or minimize soil compaction	Maintain wetland quality Maintain wetland hydrologic processes Maintain regional hydrologic connectivity
Avoid or minimize soil layer disturbance	Maintain wetland quality Maintain wetland hydrologic processes Maintain regional hydrologic connectivity
Maintain structure and function of riparian and wetland vegetation	Maintain wetland quality Maintain wetland hydrologic processes
Avoid or minimize site level run-off and erosion	Maintain wetland quality Maintain wetland hydrologic processes

Prevent sediment and pollutants from entering the wetland	Maintain wetland quality Maintain wetland hydrologic processes
Avoid or minimize invasive species introduction and/ or spread	Maintain wetland quality Maintain wetland hydrologic processes

These objectives are aligned with many current mandatory (legal) or voluntary (certification) forest management guidance in Canada. In this chapter we identify potential adverse effects of forest management activities on wetlands and the importance of avoidance or minimization. Where applicable, we reference related legal or certification requirements. In Chapter Six we describe suggested planning related practices to aid in meeting these objectives. Operational practices will be addressed in future documents.

Refer to Appendix 5 for additional information on legal and certification requirements relating to water flow.

Wetland stewardship objectives and Canadian forest certification

- SFI 2015-2019 Forest Management Standard: Objective 3. Protection and Maintenance of Water Recourses: To protect the water quality of rivers, streams, lakes, wetlands and other water bodies through meeting or exceeding best management practices
- FSC Canada Standard (Draft 2): Criterion 6.3. The Organization* shall* identify and implement effective actions to prevent negative impacts of management activities* on the environmental values*, and to mitigate and repair those that occur, proportionate to the scale, intensity and risk* of these impacts. (C6.1 P&C V4)
- FSC Canada Standard (Draft 2): Criterion 6.7. The Organization* shall* protect or restore* natural watercourses, water bodies*, riparian zones* and their connectivity*. The Organization* shall* avoid negative impacts on water quality and quantity and mitigate and remedy those that occur.
- CSA Z809-16 Sustainable Forest Management: 6.3.3 Criterion 3. Soil and Water. Conserve soil and water resources by maintaining their quantity and quality in forest ecosystems.

Maintain wetland surface and subsurface water flow

Blocking or disrupting wetland surface and subsurface flows can result in flooding upstream of the blockage and drying downstream of the blockage (Mader 2014; Robinson et al. 2010; Daigle 2010). Changes may be gradual or sudden. Altering flow can disrupt the interconnectedness of wetland systems, and changes to the quality and quantity of downstream water flows have the potential to alter plant and animal communities (Daigle 2010; Luce and Wemple 2001). Flooding upstream of a blockage may cause significant ecological damage such as mature woody vegetation dying off due to a rise in the water table.

Failing to consider wetlands (including wetland type) as part of forest harvest access planning, design and construction can result in altered water flow if the design and hydrologic conditions don't match (Partington et al. 2016). Infrastructure that may alter wetland hydrology includes roads, trails, landings, and stockpile sites.

Example wetland water flow may be impeded if a resource road crosses a wetland or wetland complex and the crossing design and construction fail to provide sufficient water conduits (e.g., culverts) to accommodate water flow during dry and wet years. Wetlands with slow lateral water flow (i.e. fens) or with seasonally fluctuating water flow (i.e. swamps) may pose particular problems. The subsequent ponding that can occur along the road can degrade the roadbed that can result in a soft road surface and rutting due to saturation which increases maintenance costs and reduces road safety.

Avoid or minimize soil compaction

Wetland soils are typically saturated and have weak bearing capacity, characteristics that make them especially prone to rutting, erosion, and compaction during activities such as road construction or timber harvest (AAFC 2007, Nugent et al. 2003). As such, wetlands have a greater potential for damage compared to upland sites. Lasting adverse effects of soil compaction include:

- increased bulk density,
- decreased porosity, and
- decreased hydraulic conductivity (Batey and McKenzie 2006; Whalley et al. 1995)

These changes may increase the potential for soil erosion and lead to changes in landscape hydrology such as enhanced overland flow and raised water tables, as well as changes in baseflow (Mallik and Teichert 2009). Compaction can occur regardless of the season, but adverse effects are most severe for unfrozen wet soils which have lower resistance compared to dry soils (AAFC 2007). Soil compaction can also occur on winter roads, which are typically thought to be less susceptible to compaction. Strack et al. (2017) found that winter roads through peatlands had higher bulk density, shallower water table, earlier thaw, and higher graminoid cover compared to an adjacent peatland.

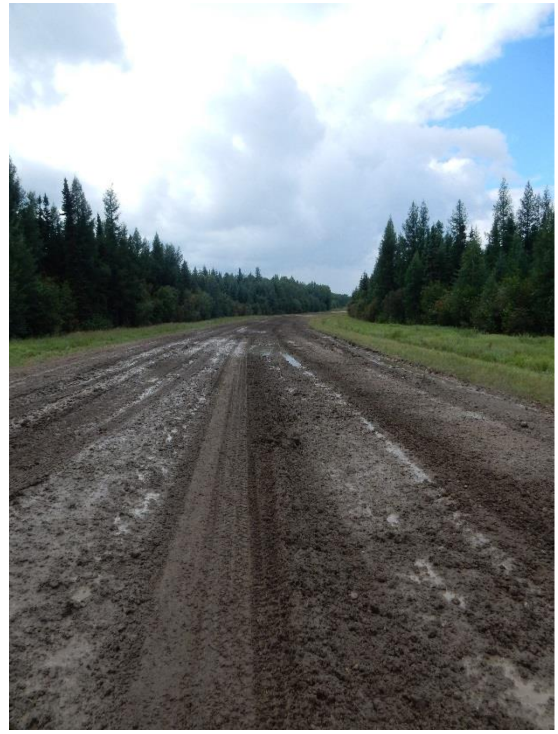


Figure 16. Examples of soil compaction and rutting from off road vehicles along powerline right-of-way near Grande Prairie, Alberta (left) and from highway vehicles on access road near Wabasca, Alberta (right).

Because compaction can reduce the ability of soil to retain and transmit water, compaction can potentially alter natural wetland hydrology (Soon et al. 2000). Altered wetland hydrology due to soil compaction is likely to be more severe in peatlands due to the high compressibility of peat compared to mineral soils. Compaction also reduces the soil's water holding capacity and can impede plant establishment and development including impeding root growth, air infiltration, emergence, and access to water and nutrients (Whiting et al. 2014; AAFC 2007). Soil compaction in areas of plant growth can damage vegetation and existing plant (including tree) roots (Lantagne et al. 1998).

Compaction from heavy equipment (e.g., logging trucks, loaders, skidders or feller bunchers) working in or near wetlands or as the result of other activities (landings, camps, or storage areas) can initiate a negative cycle whereby a lack of established vegetation leads to erosion and loss of organic material required for vegetation to re-establish. Further, plants that do establish may experience stunted growth from nutrient and water deficiencies, and badly formed roots from an inability to properly penetrate the soil (Kozlowski 1999; DeJong Hughes et al. 2001).

Avoid or minimize soil layer disturbance

Maintaining healthy soil is critical for maintaining functional forest ecosystems. Soil is the main source of nutrients for all plant species, supports above and below ground animal biodiversity, and along with the plants it supports, transmits water across the landscape. Different soil layers, or horizons, have different physical and biogeochemical properties that support different processes and functions. Disturbing (e.g., by mixing) horizons can have potential negative implications for plant growth.

Some forest management activities, such as road construction, may disturb soil layers depending on design and construction. For example, road construction through a peatland may involve removing surface vegetation and potentially removing and/or compacting the organic layers (e.g., Pilon 2015). If soil layers are mixed during removal, storage, or replacement there are potential adverse effects to chemical and physical soil properties (Soon et al. 2000; Culley et al. 1981). Potential effects include changes to (Ivey and McBride 1999; Naeth et al. 1993; Olson and Doherty 2012; Soon et al. 2000):

- soil bulk density
- permeability
- temperature
- pH
- organic matter content
- nitrogen content

Mixing soil layers can be especially damaging in organic wetlands (bogs and fens) where it may compromise the unique properties of peat, altering hydrology and vegetation growth (Ryder et al. 2004).

Like compaction, rutting can disturb soil layers and can be a common occurrence in wet soils where the soil strength is not sufficient to support the load of vehicle traffic (MDNR and MDEQ 2009). If skid trails or landings are in or near wetlands, rutting and ponding of water can occur if logging trucks, loaders, or skidders break through the surface and bring underlying peat to the surface (Sheehy 1993). Ruts can act as channels for storm and surface water with adverse effects (e.g., erosion and sedimentation) expected if channeling is oriented towards an open water body or other low lying areas including wetlands (MDNR and MDEQ 2009).

Altered wetland hydrology due to soil rutting and compaction is likely to be more severe in peatlands due to the high compressibility of peat compared to wetlands dominated by mineral soils. Like compaction, soil rutting in areas of plant growth can damage vegetation and existing plant (including tree) roots (Lantagne et al. 1998). Plants that do establish may experience stunted growth from nutrient and water deficiencies, and badly formed roots from an inability to properly penetrate the soil (Kozlowski 1999; DeJong Hughes et al. 2001).

Maintain structure and function of riparian and wetland vegetation

Vegetation is a defining feature of wetlands and riparian areas that support important ecosystem services such as water filtration, soil stabilization, and habitat provisioning for a variety of wetland dependent species. For example, riparian vegetation associated with wetlands may act as a natural barrier to sediment-laden runoff from roadways and work areas where soils are exposed, slowing flows and allowing sediments to precipitate out of the water before it enters the water column. Removing or altering significant amounts of wetland vegetation can result in:

- exposed banks vulnerable to erosion and sedimentation
- loss or alteration of the ecosystem services provided by wetland vegetation
- sedimentation, altering plant community structure
- decreased water holding capacity by the wetland
- damage to rare ecological communities and rare plant habitats that may be challenging to re-establish

Wetland vegetation such as cattail, grasses, sedges, shrubs, and mosses should be disturbed as little as possible to maintain their functions and to promote recovery. Where trees and woody vegetation need to be removed for mobility or safety reasons, retaining the ground layer (surface layer/root mat) will help promote recovery. Retaining plant communities with minimal soil disturbance will also assist restoration.

Products used to manage vegetation (e.g., pesticides) can have negative effects on wetlands. If not properly applied and controlled, the addition of pesticides and fertilizers to wetlands (e.g., through runoff) has the potential to disrupt the nutrient cycling, damage wetland organisms, enter the groundwater system and can be transported through the watershed. If pesticides are used, employ pesticides approved for use in aquatic ecosystems or employ non-aquatic pesticides with adequate buffering of aquatic (including wetland) ecosystems.

Avoid or minimize erosion and sedimentation

Vegetation clearing and construction activities may result in the exposure and erosion of upland soils and transportation of sediments into wetlands and other water bodies. In addition, locating roads or skid trails through wetlands and operating harvesting equipment in or near wetlands may result in soil disturbance and subsequent erosion and sedimentation.

Figure 17. Example of soil erosion at wetland crossing

Erosion can be caused by water (*e.g.*, rainfall or run-off) or wind and is more likely to affect dry, compacted, and previously eroded soils (Ritter 2012). Erosion can affect soil quality, structure, stability, and texture making it more difficult for plants to establish due to loss of nutrients and organic matter, and for the soil to retain moisture due to low surface permeability and textural changes affecting water holding capacity (Ritter 2012; Mallik and Teichert 2009).

Sedimentation from forestry practices (e.g., road construction, log skidding, prescribed burning and scarification) can potentially influence wetland and water body water quality and the health of aquatic life. Sedimentation can alter the plant community structure either directly, by suffocating native plant species, or indirectly by decreasing the water volume or the duration of time that water is present on the land (Dowling 2010). Sedimentation can also reduce seedling establishment and lower community biomass, diversity, and richness (Mahaney et al. 2005).

High sediment loading on a wetland can affect aquatic vertebrates and invertebrates such as by burying bottom dwelling organisms and eggs laid on the wetland floor (Gleason et al. 2003). Increased turbidity levels (suspended sediment) will reduce light penetration, increase water temperatures, reduce plant growth, and reduce visibility for fish and other predatory species.

Prevent pollutants from entering the wetland

Equipment and vehicles are potential sources of spills of oil, gas and other fuels. If a spill occurs, the extent of wetland contamination will depend on amount and type of product spilled, wetland connectivity, and rate and direction (vertical vs. horizontal) of water movement.

Avoid or minimize invasive species introduction and/or spread

Managing the introduction and spread of invasive species is an important component of sustainable forest management. Invasive species are non-native species that once introduced are able to spread and often cause socio-cultural, economic, or environmental harm. Refer to Table 4 for a list of invasive species that may be of concern to forest managers in Canada's western boreal. Riparian areas are vectors of invasive species because natural hydrologic cycles expose sediment and provide colonization opportunities (Naiman et al. 2005). As well, disturbing wetland vegetation and exposing wetland soils may facilitate the spread of invasive species. A study examining sedimentation on wetlands soils and vegetation in the Dog River Watershed found the spread of invasive species was directly affected by sedimentation rate (Dowling 2010).

Table 4. Invasive species that may be of concern to forest managers working in Canada's western boreal forest. Table does not cover an exhaustive list of every possible species but identifies key species of concern. Aquatic species are of highest interest from a wetland perspective.

Insects	Pathogens	Plants	Aquatic
Pine shoot beetle	Scleroderris canker	Garlic mustard	Faucet snail
European pine sawfly	White pine blister	Common toadflax, Dalmatian toadflax, Yellow toadflax	Zebra & quagga mussel
Bark beetle	Dogwood anthracnose	Tall buttercup	Phragmites
Mountain pine beetle (native to Canada, but expanded beyond historic range)	Dothichiza canker of poplar	Oxeye daisy	Variable-leaf watermilfoil
Larch sawfly	European larch canker	Giant hogweed	Curly leaf pondweed
Rusty tussock moth	Poplar leaf rust	Wild parsnip	Spiny waterflea
European spruce sawfly	Willow scab	Perennial sow thistle, Nodding thistle, Bull thistle	Hydrilla
Balsam woolly adelgid	Dutch elm disease	Purple loosestrife	Salt cedar
European gypsy moth		Canada Thistle	European frog-bit
Ambermarked birch leafminer		Spotted knapweed	Yellow flag iris
Birch leafminer		Scentless chamomile	Flowering rush
Emerald ash borer		Common tansy	Himalayan balsam
		European buckthorn	Reed canary grass
		Japanese brome, Downy brome	Water hyacinth
		St. John's wort	Narrow leaved & hybrid cattail
			Rusty crayfish
			Elodea
			Water soldier

Comprehensive lists of invasive species of provincial concern can be found by province:

- Invasive Species Council of Manitoba - http://invasivespeciesmanitoba.com/site/index.php?page=aquatic-species
- Saskatchewan Invasive Species Council – http://www.saskinvasives.ca/
- Alberta Invasive Species Council – https://www.abinvasives.ca/fact-sheets#!prettyPhoto
- BC Invasive Species Council - http://bcinvasives.ca/

Forest management activities that involve bringing in equipment and crews from different sites are a potential mechanism for spread. However, forestry is rarely the only user on the land base, other industries and individuals can also be sources of spread and can be more difficult to control.

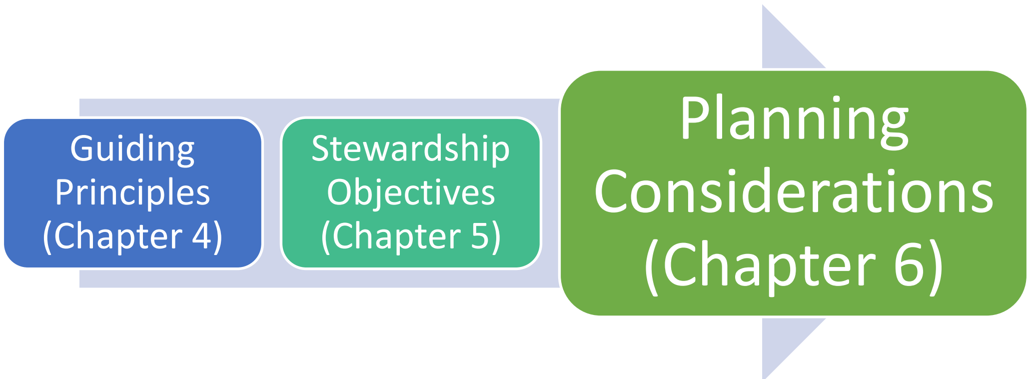
- Roads built for forest management activities can facilitate expanded and unmanaged access by recreational vehicles (e.g., ATVs, trucks, snowmobiles, dirt bikes, etc.) if access points and use of roads and trails aren't actively managed.
- Resource roads may increase access to other linear corridors such as pipeline ROWs, seismic lines, or transmission line ROWs, providing additional corridors for spreading species into more remote locations.

Figure 18. Examples of terrestrial and aquatic invasive species clockwise from top left: Purple loosestrife, Faucet snail, Giant hogweed, Leafy spurge, Invasive phragmites, and flowering rush.

Chapter Five Summary

- In this chapter we describe seven wetland Stewardship Objectives that help support the Guiding Principles described in Chapter Four. We developed the objectives to address potential adverse effects of forest management activities on wetlands.
- Meeting the objectives will demonstrate wetland stewardship by forest companies and will help achieve key wetland and environmental outcomes.
- Objectives are aligned with many current mandatory (legal) and/ or voluntary (certification) forest management requirements in Canada including all three (FSC, SFI, and CSA) forest certification standards.
- Objectives described in this chapter include: maintaining surface and subsurface water flow; avoid or minimize soil compaction; avoid or minimize soil layer disturbance; maintain structure and function of riparian and wetland vegetation; avoid or minimize erosion and sedimentation; prevent pollutants from entering the wetland; and avoid or minimize invasive species introduction and/ or spread.
- Planning considerations to help address these objectives are introduced in Chapter Six and specific operational practices will be addressed in a separate document on operational practices for wetland stewardship and forest management.

Chapter Six: Planning Considerations



Key decisions for successful forest management are made in planning and design phases of a project. The purpose of this Chapter is to provide forest planners with strategies, tools, and techniques to help meet the wetland stewardship principles and objectives described in Chapters Four and Five. Operational practices will be the focus of a future FMWSI project. Planning considerations described in this section may be currently used by forest companies, while others may be new. Planning considerations are grouped into three categories: (1) considerations for avoiding potential adverse effects to wetlands; (2) considerations for minimizing potential adverse effects to wetlands; and (3) considerations to help improve wetland habitats.

Example of a wetland mitigation hierarchy, Government of Alberta.

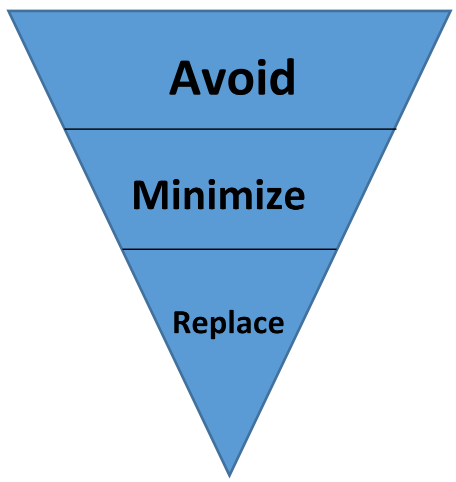


Figure 19. Avoidance is highest priority and companies must demonstrate their effort to avoid adverse effects to wetlands when conducting activities. Minimization is the second priority, when the proponent has demonstrated that avoidance isn't possible. Proponents must demonstrate that they are reducing adverse effects on wetlands to the smallest practicable degree. Replacement is required when permanent adverse effects to a wetland cannot be avoided or minimized.

Bringing together guiding principles, stewardship objectives, and planning considerations

Many of the planning considerations discussed in this Chapter support all principles and objectives. In particular, avoidance considerations will in most cases meet all objectives and principles. Minimization considerations will help meet some objectives and principles depending on the specific approaches that are used. Table 5 links planning considerations covered in this Chapter to the objectives and principles that they support. Planning considerations in this Chapter focus on the 'avoid' and 'minimize' levels of the mitigation hierarchy.

Table 5. Summary of planning considerations, objectives of the planning considerations supports, and principle(s) of the planning considerations including avoidance and minimization considerations.

Planning considerations	Objectives the planning consideration supports	Principle(s) the planning consideration
Avoidance considerations		
Map the distribution of wetlands on the landscape by type	Supports all objectives: • Maintain surface and subsurface water flow • Avoid or minimize soil compaction • Avoid or minimize soil layer disturbance • Maintain structure and function of riparian and wetland vegetation	Supports all principles: • Maintain wetland quantity • Maintain wetland quality • Maintain hydrologic processes • Maintain hydrologic connectivity
Avoid new disturbances to wetlands by participating in integrated land management planning		
Avoid new disturbances to wetlands by locating new infrastructure near or on existing disturbances and by planning access routes to accommodate future development needs		
Prioritize avoidance of wetland types based on ecological, social, and economic criteria		
Minimization considerations		
Consider timing, location and equipment when working in or near wetlands in relation to the following: • Climate • Bedrock and surficial geology, soils • Topography and drainage network	Supports all objectives	Supports all principles

Consider the location of planned access, harvest, and renewal activities in relation to wetlands and the following: • key attributes and flow characteristics • position of wetland in the watershed • wetland connectivity	Supports all objectives, particularly: • Avoid or minimize blockage or disruption of wetland surface and subsurface water flow	Supports all principles, particularly: • Maintain hydrologic connectivity
Locate wetland crossings to minimize disturbance	Supports all objectives	Supports all principles
Consider the wetland type when choosing the wetland crossing	Supports all objectives, particularly: • Avoid or minimize blockage or disruption of wetland surface and subsurface water flow	• Maintain hydrologic connectivity
Schedule activities to occur during favourable weather conditions (e.g. winter operations, shutting down operations during spring runoff or heavy rain events)	• Avoid or minimize soil compaction • Avoid or minimize soil layer disturbance • Prevent sediment and pollutants from entering the wetland • Avoid or minimize blockage or disruption of wetland surface and subsurface water flow	• Maintain wetland quality, maintain hydrologic processes, maintain hydrologic connectivity
Establish vegetated zones around wetlands	• Avoid or minimize soil compaction • Avoid or minimize soil layer disturbance • Prevent sediment and pollutants from entering the wetland	• Maintain wetland quality
Establish storage sites and recovery plans for petroleum products and other pollutants	• Prevent sediment and pollutants from entering the wetland	• Maintain wetland quality
Plan to minimize invasive species introductions and spread	• Avoid or minimize invasive species introduction and/ or spread	• Maintain wetland quality

Planning to Avoid

What does avoidance mean?

Avoidance is first stage in many environmental mitigation strategies and/or policies as the primary and preferred response to achieving management objectives (e.g., Gardner et al. 2012; AESRD 2013; British Columbia Ministry of Environment 2014a). Avoidance, as a wetland mitigation strategy, can be defined in a number of ways. For example:

> *Harvesting treed swamps is not a prevalent forestry practice in western Canada. However, treed swamps often contain merchantable trees that can be targeted for harvest. Harvesting treed swamps is not addressed as part of the planning considerations described in this Chapter.*

- The Government of British Columbia's Environmental Mitigation Policy defines avoidance as the "means to fully avert any potential impact on one or more environmental components resulting from a project or activity" (British Columbia Ministry of Environment 2014b).
- The Ramsar Convention on Wetlands indicates that "avoiding wetland impacts involves proactive measures to prevent adverse change in a wetland's ecological character through appropriate regulation, planning or activity design decisions" (Gardner et al. 2012).
- The Government of Alberta's Wetland Policy defines avoidance as "to prevent impacts to a wetland by identifying an alternate project, activity, design, or site, or abandoning the project or activity altogether or by denial of an application by the regulator" (AESRD 2013).

The Government of Alberta's Wetland Policy states that "avoidance is the most efficient and effective mitigation strategy, as it eliminates the potential risks and inherent uncertainty of other mitigation practices" (AESRD 2013). The best way to ensure that wetlands are not adversely affected by forestry operations and to meet all wetland stewardship principles and objectives discussed in this document is to avoid working in or near wetlands.

Generally, with the exception of merchantable treed swamps, forest managers avoid wetlands where possible because of potential cost, safety issues, and regulatory or certification requirements. However, lack of awareness and understanding of boreal wetlands may result in some wetland types being avoided more than others.

- Because some water is typically present at the wetland surface, shallow open water, marsh and other open wetland types (open bog and graminoid fens) are easier to identify remotely and on-the-ground.
- Treed wetlands, including swamps, treed fens and treed bogs are more prevalent in much of the boreal forest compared to open water wetlands, and can be more difficult to identify.

Fish bearing habitats

Shallow open water wetlands are potential fish bearing habitat and forest operations will tend to be more cautious about activities in and around these wetland types. Because treed and shrubby wetlands are not often recognized as fish bearing habitat, or as contributing to the health of fish bearing habitat, there may be less regulatory incentive to avoid negatively affecting these wetlands.

How can avoidance be achieved through planning?

Avoidance is typically achieved at the planning stage by determining the abundance, type, and location of wetlands within the area of interest and then choosing locations for access and timber harvesting that are not in or near wetlands. Planning to avoid is done remotely at the landscape planning level and later by ground-truthing as part of operational planning.

The following sections describe planning practices to consider to avoid potentially adverse effects to wetlands. Each planning practice includes a description of the practice and rationale, reference to supporting information (i.e. policy or legal requirements, certification requirements, and/ or supporting literature), application, and case studies of application.

Map the distribution of wetlands on the landscape by type

Description/ Rationale:	Knowing where wetlands are located is critical to the planning process. An accurate understanding of wetland locations allows forest managers to make effective decisions on if, how, and when to avoid wetlands. As discussed in Chapter Two, different boreal wetland types have different ecological and hydrological characteristics. Maps that identify wetlands by type can be used to help prioritize wetlands for avoidance (*see planning consideration 4*), determine appropriate minimization techniques if wetlands can't be avoided, and identify and potentially prioritize areas for wetland restoration or reclamation. Having access to accurate and precise data is critical to making good decisions. Not knowing where and what type of wetlands exist in a forest management area can potentially hinder harvest planning and subsequent operations, as well as wetland stewardship efforts.
Supporting information	Refer to Appendix 6, section 1.1
Application	Maps can help improve harvest planning and operations but are only as effective the data used to build them. Maps that are developed from an inventory designed for forestry or different purposes may not identify wetlands as well as a specific wetland inventory. For example, wetlands are not specifically interpreted or identified within the Alberta Vegetation Inventory (AVI) and are often placed into the "non-forested vegetated land" classification that includes: closed shrub, open shrub, herbaceous - grassland, herbaceous –forb, and bryophyte (AESRD 2005). Thus wetlands, especially those with shallow open water or trees, are often underrepresented in AVI-based forest landscape assessments. In vegetation-based inventories treed wetlands, particularly swamps, are often referred to as lowlands and are included as part of tree stands. Understanding the limitations of available inventory products is important in determining how best to address any gaps in wetland information. Wetlands can be mapped or delineated using aerial photography, satellite imagery, modeling, or through on the ground field data collection. For example: • Aerial photography has been used to map wetlands in Canada (Murphy et al. 2007, Watmough and Schmoll 2007). • The Canadian Wetland Inventory (Ducks Unlimited Canada 2016), DUC's Enhanced Wetland Classification (Smith et al. 2007a) was developed using multi-spectral remotely sensed imagery. • The Alberta Merged Wetland Inventory (Government of Alberta 2017) is a compilation of different wetland inventories developed for different regions of the province. The EWC at the five class level covers the province's Green Zone. • LiDAR has been used in Wet Areas Mapping projects in a number of locations across Canada (Forest Watershed Research Center 2017). While not a wetland inventory per se; wet areas mapping helps to more accurately delineate wetlands from uplands (Murphy et al. 2008).

	A detailed explanation of the DUC wetland inventory, the Alberta Merged Wetland Inventory, and the Wet Areas Mapping project can be found in the Tools section of this Chapter. Wetland inventories generated using aerial photography, satellite imagery or modeling should be ground-truthed during road layout and pre-harvest surveys. When performing an on-the-ground assessment it is important to remember that wetlands go through wet and dry cycles and the presence or absence of surface water is not always predictive of wetland presence. There are a number of indicators that can be used to determine whether you are in a wetland or upland, and tools to help you determine the type of wetland you are in (see Chapter Two). **Mapping methods** Aerial Photography: Interpreting photographs is a difficult, time consuming, and costly practice and wetlands may not be well captured using this type of traditional forest mapping and identification technique alone. Multi-spectral Remote Sensing: Observes radiation typically in the visible and infrared portions of the electromagnetic spectrum, in several discrete bands of data. This type of imagery is used for DUC's EWC. LiDAR Remote Sensing: Active remote sensing technique that measures distance by illuminating the Earth's surface with a laser and analyzing the reflected light. Can be used to spatially predict water flow patterns, wet and dry areas, and the depth to water in areas of interest from digital elevation models (e.g., Wet Areas Mapping).
Application example	**Mapping wetlands on Millar Western's Forest Management Area (FMA)** Wetlands are not specifically interpreted or identified within the Alberta Vegetation Inventory (AVI). Using the AVI, Millar Western Forest Products Ltd. identified approximately 40ha of wetlands in six locations on their FMA in the categories of – closed shrub, herbaceous forbs, and herbaceous grassland. In developing their 2017-2027 Detailed Forest Management Plan (DFMP) Millar Western asked for DUC's assistance to map wetlands on their FMA. Based on DUC's wetland inventory (EWC), wetlands make up 23% (109,718ha) of Millar Western's FMA. One of the Forest Management Units is over 40% wetlands. Fens followed by swamps are the most prevalent wetland type on the FMA. As was demonstrated by this comparison of AVI and EWC data, treed wetlands, such as swamps and fens, are often underrepresented in forest landscape assessments based on AVI data.

Avoid new disturbances to wetlands by participating in integrated land management planning

Description/ Rationale	Integrated land management (ILM) is the strategically planned approach to managing and reducing the human-caused footprint on public land (AEP 2018). Working with other land users to coordinate site selection and design planning, construction and use of new development, maintenance and use of existing developments and remediation or restoration of decommissioned areas can help avoid or minimize the extent and duration of legacy disturbances. Sharing infrastructure can also reduce construction, maintenance and decommissioning costs. For example, forest managers can coordinate resource access planning with others at the landscape level, forest management plan/unit level and operational site level to avoid or minimize new disturbances to wetlands (Alberta Environment and Parks, 2015).
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 1.2
Application	To be effective, ILM should include planning over space and time. Planning should incorporate current and future needs and consider a range of potential future situations. ILM should be done at the forest management plan level and at larger landscape level if appropriate. Planning should identify: • Activities taking place on the landbase • Organizations and individuals working on the landbase • Where and when there is the need to collaborate with others working on the landbase Collaboration should consider how the existing footprint is used, future footprint needs, opportunities to remove or reduce the footprint, and ways to coordinate activities and infrastructure.
Application examples	Though ILM makes sense intuitively and it is promoted as a tool to reduce adverse effects of industry activities, its application is not well documented in the literature. Some examples of application include: • It is expected that the Kakwa Copton Industrial Corridor plan, an integrated planning initiative by forestry and oil and gas companies in west-central Alberta, will result in an overall footprint ~45% less than what would have occurred without the plan (Government of Alberta 2012). • Alberta Pacific Forest Industries Inc. (AlPac) worked with two oil and gas companies (Opti Canada Incorporated and Nexen Incorporated) to reduce overall disturbance at the site of a new oilsands construction project in north-eastern Alberta. By participating in integrated planning, these companies were able to share much of same footprint and were able to harvest 30% fewer trees (Government of Alberta 2015). • ConocoPhillips Canada Ltd. worked with AlPac to reduce their footprint at the Surmont Oil sands project near Fort McMurray, Alberta. ConocoPhillips found that coordinating activities with AlPac would result in "*a 34% reduction in road access and a 16% reduction in areas cleared for facility development*" compared to working independently (Canadian Association of Petroleum Producers 2004).

Avoid new disturbances to wetlands by locating new infrastructure projects near or on existing disturbances and by planning to accommodate future development needs

Description/ Rationale	New disturbances to wetlands can be avoided by using existing infrastructure (e.g., roads and trails) or re-using sites of existing or recent disturbances. For example, disturbance may be reduced by locating camps and other facilities near existing access roads or other industrial developments. Planning access routing to accommodate future development needs will ensure that existing infrastructure can be used or reused, reducing the need for further disturbance on the landscape.
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 1.3
Application	Like ILM, utilizing existing infrastructure and disturbances requires planning over large space and lengths of time to be effective. In addition, this practice requires quality information about the location and type of disturbance on the landbase, generally in the form of maps that can be incorporated into desktop planning. There are times where re-using existing infrastructure and disturbances may not be the preferred option, this may include: • If the original infrastructure was poorly located and/ or constructed • There are safety concerns with existing infrastructure or disturbance (e.g., crosses deep peat deposits, poor quality)
Application example	**Sunpine Forest Products road and pipeline route** Sunpine Forest Products received an initial energy application for a proposed road, pipeline route and wellsite on their lease area; however, Sunpine identified integration conflicts for the proposed pipeline route. In response, "an integrated solution was proposed where the two routes (future forestry road and pipeline route) followed the same routing as opposed to the unintegrated route". Sunpine saved $390,000 and the energy company save $780,000. Integrating the routes avoided an additional 5km of linear feature, eliminated one stream crossing, and eliminated access to a critical wildlife area (Government of Alberta 2012).

Prioritize wetlands for avoidance based on ecological, social and economic factors

Description/ Rationale	If wetland avoidance is not possible and forest companies have to choose which wetlands to avoid, consider prioritizing avoidance based on ecological, social, and economic priorities. For example, forest companies may want to prioritize avoiding wetlands that are habitat for species of conservation concern (e.g., caribou, yellow rail) or wetlands identified as high value by government policy and/or legislation (e.g., Provincially Significant Wetlands in Ontario, "A" value wetlands in Alberta). Qualities that may be considered when prioritizing wetlands for avoidance such as rareness, flow characteristics, reclamation difficulty, and others are listed in Table 6.
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 1.4
Application	Prioritizing wetlands for avoidance can be challenging due to local and regional variation. Developing a decision framework based local and regional needs and taking into consideration the values listed in Table 6, will help companies determine their priorities. For example, companies could develop a check list, where wetlands with the most checks would be prioritized for avoidance. Criteria for how a wetland is best developed and prioritized should be determined by the individual forest company unless there are government or certification requirements that need to be met. ***Learning from wetland reclamation prioritization*.** Some jurisdictions have developed or are developing criteria for prioritizing wetland reclamation, this information could be used directly or used to guide a system for prioritizing wetland avoidance. Examples of jurisdictions that have done some work on prioritizing or defining qualities to prioritize include Minnesota, Alberta under the wetland policy, and Ontario's provincially significant wetlands.
Example of application	Boreal wetlands, particularly treed bogs and fens, within caribou ranges can provide good quality wintering and calving habitat for caribou. Because of caribou's threatened status across much of Canada's boreal, wetlands that provide high quality caribou habitat may be prioritized for avoidance within caribou ranges.

Table 6. Recommended ecological considerations for prioritizing wetlands for avoidance.

Wetland values to consider	Reasons for importance
Complexes	In areas with low topographic relief, wetlands are often highly connected resulting in a large expanse or complex of several wetlands transitioning from one wetland type to another across the landscape. Several wetland classes can be associated with an open water pond or stream or adjacent to upland sites. These wetland riparian areas are typically defined as transition areas between open water and uplands. Soil moisture and other properties are expected to change across a transition area reflecting several wetland types. For example, the transition from an open water wetland may include emergent and/or meadow marshes, treed or open fens, shrub or conifer swamps or any combination of these. Studies have shown that wetland complexes are high in biodiversity (e.g., Brown and Dinsmore 1986; Fredrickson and Reid 1988; Fairbairn and Dinsmore 2001 McKinstry and Anderson 1994, 2002; Gammonly 2004; Rumble et al. 2004; Tessmann 2004). Because boreal wetland complexes can contain several wetland types they can encompass all of the considerations below. As a result, wetland complexes could be prioritized highest for avoidance.
Rarity	To maintain the diversity of habitat types on the landscape, special effort may be needed to retain rare wetland types. In Canada's boreal forest shallow open water and marsh wetlands tend to be rare compared to other wetland types. Rarity should be determined by calculating wetland type coverage using tools such as wetland maps. Rarity may depend on the scale (FMU, FMA, landscape, etc.) at which it is assessed.
Waterfowl abundance	Waterfowl are an important part of wetland ecosystems and areas with high waterfowl abundance can often indicate good habitat for other aquatic species. Waterfowl are more likely to be found in or near open water and marsh wetlands but may nest in a variety of wetland types. DUC has developed maps of waterfowl distribution for each of the three nesting guilds and for all species.
Species of special consideration	Wetlands that provide important habitat for species of interest, particularly for subsistence species, rare species, species at risk, species of cultural value to Indigenous peoples, and species identified either through legal or certification requirements.

	Examples of potential species of interest include caribou, yellow rail, black tern, trumpeter swans, and moose.
Reclamation	Some wetland types are more challenging than others to reclaim. Peatlands (bog and fen) reclamation is still in the early stages of research. Reclaiming peatlands, as may be required following road decommissioning, generally requires additional time, money, and expertise compared to restoring mineral wetlands.
Government policy and/or legislation value	In some jurisdictions governments have prioritized wetlands or defined criteria for valuing wetlands. For example: • The Ontario Wetland Evaluation System is used to determine Provincially Significant Wetlands in Ontario • The Alberta Wetland Policy "A" Classified wetlands – Alberta As well, provincial recovery plans for species of special consideration, such as caribou, may identify valuable wetlands.
Hydrologic function	Some wetlands have been determined to be important to the hydrologic functioning of the watershed by acting as water source areas. According to Devito et al. (2017) bogs, fens, and swamps are important water sources that can help support upland forests, particularly in dry years. This may contribute to forest productivity (as discussed in Chapter Three).
Hydrologic impairment	All wetland types, including those referred to as 'stagnant' (Chapter Two, Appendix 7) have the potential to move water and are at risk of hydrologic impairment. However, because of the dynamic water movement in fens (laterally flowing) and swamps (seasonal fluctuations and potential for lateral flow), these wetland types may be at greater risk of hydrologic impairment compared to other wetland types.
Carbon storage potential	Peatlands, bogs and fens, can store significant amounts of carbon. Boreal peatlands typically have peat depths between 40cm and up to several meters. Compared to other wetland types, disturbing bogs and fens has a greater potential to adversely affect carbon stores and future storage potential.

Table 7. Checklist identifying ecological, economic, and social considerations for the five major wetland classes. This information can be used when prioritizing wetlands for avoidance; however, it is up to users to determine how to apply this information. Additional information about species of concern and subsistence or cultural species can be found in Table 8.

Wetland type	Ecological							Economic		Social
	High biodiver sity	Potential habitat for species of concern (Table 8)	Potential waterfowl feeding habitat	High carbon storage/ sequestratio n	Important water source	Risk of hydro-logic impairment	Rare Wetland type	Challenge to build	Challenge to restore/ reclaim	Subsistence or cultural species (Table 8)
Wetland complex	X	X	X	X	X	X		X	X	X
Shallow Open Water	X[1]	X	X				X	X		X High value[1]
Marsh	X[1, 2]	X	X				X	X		X High value[1]
Swamp	X[1, 4]	X			X	X		X	X	X Highest ranking[1]
Fen	X[1,3, 4,5]	X	X	X	X	X		X	X	X High to moderate ranking[1]
Bog	X[1,3, 4,5]	X		X	X			X	X	X Low - moderate ranking[1]

Table 8. Species of concern and species of cultural importance for major and minor boreal wetland classes. The presence of species of concern and species of cultural importance can be considered when prioritizing wetlands for avoidance.

	Species of concern								Species of cultural importance				
Wetland type	Black tern	Horned grebe	Canada warbler	Rusty black bird	Olive sided flycat-cher	Yellow rail	Wood-land caribou	Western toad	Beaver	Muskrat	Moose	Fisher	Mink
Shallow open water		X		X					X	X			X
Marsh	X			X				Breeding	X	X	X		X
Swamp			X	X	X	X			X			X	X
Hardwood			X		X				High value[1]				
Mixedwood			X	X	X				High value[1]				
Shrub			X	X		X			Highest value[1]				
Tamarack			X	X	X				High value[1]				
Conifer			X	X	X		X		High value[1]				
Fen			X	X	X	X	X		X		X	X	X
Treed rich			X	X	X	X	X		Low value[1]				
Shrubby rich			X	X	X	X			Moderate value[1]				
Graminoid rich						X			High value[1]				
Treed poor			X	X	X	X	X		Low value[1]				
Shrubby poor			X	X	X				Moderate value[1]				
Graminoid poor									Low value[1]				
Bog			X	X	X		X	Winter-ing			X	X	
Treed			X	X	X		X		Moderate value[1]				
Shrubby			X	X	X		X		Low value[1]				
Open									Low value[1]				

[1] Ducks Unlimited Canada. 2014. Ranking Vertebrate Biodiversity in Boreal Wetland Habitats of Alberta using the Enhanced Wetland Classification System – Version 2.1. Ducks Unlimited Canada, Edmonton, Alberta.

[2] Bright, D.A. 2011. Vegetative and soil mesofaunal changes at boreal peatland field sites from produced water spills: Implications for the environmental assessment and remediation of upstream oil and gas sites. Prepared by AECOM, Victoria, BC. Accessed February 16 2018 from <http://auprf.ptac.org/wp-content/uploads/2016/04/2011-AECOM_EcologicalEffects-of-Salt-Releases-to-Boreal-Peatlands.pdf >

[3] Locky, D.A. and S.E. Bayley. 2005 Plant diversity, composition, and rarity in the southern boreal peatlands of Manitoba, Canada. *Canadian Journal of Botany*. 84: 940-955.

[4] Locky, D.A, Bayley, S.E, and D.H. Vitt. 2005. The vegetational ecology of black spruce swamps, fens and bogs in southern boreal Manitoba, Canada. *Wetlands.* 25(3): 564-582.

[5] Warner, B.G., and T. Asado. 2006. Biological diversity of peatlands in Canada. *Aquatic Sciences*. 68: 240-253.

Planning to Minimize

What does minimization mean?

Avoidance in the boreal forest is often difficult to achieve due to the high density and distribution of wetlands. As a result, forest managers should plan to minimize potential adverse effects of forest operations on wetlands. Minimizing adverse effects is often the second step in an environmental mitigation strategy (e.g., Gardner et al. 2012; Government of Alberta 2013a; British Columbia Ministry of Environment 2014a). Minimization as a component of a wetland mitigation strategy can be defined in a number of ways. For example:

- The Government of British Columbia's Environmental Mitigation Policy defines minimization as the *"means to partially avoid or reduce the level of impacts on one or more environmental components resulting from a project or activity*" (British Columbia Ministry of Environment 2014b).
- The Government of Alberta's Wetland Policy defines minimization as "*reducing negative impacts on wetlands to the smallest practicable degree during the planning, design, construction, and operational stages of development, and when conducting activities that may harm wetlands*" (Government of Alberta 2013a).

How can minimization be achieved through planning?

Careful up-front planning can minimize adverse effects of road infrastructure, forest harvest, and forest renewal while assisting in reducing maintenance, decommissioning, and reclamation requirements. Incorporating wetlands in landscape and operational planning can help reduce the duration, size, intensity, and/or frequency of potential adverse effects in or near wetlands. The following section describes practices to consider when planning to minimize potentially adverse effects to wetlands associated with forest operations.

Consider timing and location when working in or near wetlands in relation to the following:

- Climate
- Bedrock and surficial geology, soils
- Topography and drainage network

Climate: Regional and local climate conditions influence the amount of runoff that can be expected, water storage potential, and hydrologic grouping (direction, speed, and other flow properties). Climate can vary through time and so it is important to incorporate the climate cycle (e.g., wet period vs. dry period) into planning decision making. For example, during a dry period the amount of water flowing through a fen may decrease, giving the appearance of a small fen with slow and minimal water movement. However, during a wet period the fen may increase in size with an accompanying increase in the amount and speed of water movement. When making decisions about access routes and crossing designs it is important to make choices that would perform well in both dry and wet climate periods.

Bedrock geology, surficial geology, and soils: The type of bedrock geology, surficial geology, and soils in your planning area will influence the amount and type of water flow on the landscape. For example, the potential for runoff is greater in areas with impermeable bedrock such as in the Boreal Shield Ecozone, compared to areas with more porous bedrock as is found in the Boreal Plains Ecozone. In addition, areas with relatively shallow, fine grained/ clay surficial geology are more likely to be dominated by surface water flow than by ground water and subsurface flows. Wetland soils, particularly peat soils, have higher organic content than upland soils resulting in greater water holding capacity. Saturated organic soils have poor bearing capacity and as a result have a high potential for settlement, compaction and rutting

Topography and drainage network: In some areas, topography is an important driver of water movement. For example, where wetlands are located in areas of steep slopes, such as British Columbia's interior mountains, significant run off and fluctuating water flows can be expected. These factors should be considered when planning access corridors. In contrast, wetlands are more likely to be connected (share water flow) in areas of low relief (gentle slopes). The importance of wetland connectivity in relation to planning is outlined in the next section.

Description/ Rationale	Wetlands in forests are influenced by a number of factors including climate, bedrock and surficial geology, soil type and depth, and topography and drainage network. Understanding these factors will assist planners and operators in determining where, when and how to work in or near wetlands to reduce potential adverse effects. For additional information on climate, bedrock geology, surficial geology, soils, topography and drainage, see below.
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 2.1.
Application	Climate information can be used to identify times in the year where conditions are typically wetter or drier to help minimize challenges associated with working in wetlands during wet periods. In addition, climate information can be used to identify periods when the ground is expected to be frozen. Historical climate

	data can be found on the Government of Canada website, and other provincial sources of climate information can be found here: • BC station data • Alberta Climate Information Service • Not available for Saskatchewan or Manitoba Surficial geology maps are not always available for all areas; however, they can be a useful tool for better understanding the landscape. • BC surficial geology maps • Alberta bedrock and surficial geology maps • Saskatchewan surficial geology maps • Manitoba surficial geology maps Topography maps can also be used to help plan to work in and around wetlands. In particular, topography maps can be used to identify areas with steep relief that may present operational challenges. • BC topographic map viewer • Alberta topographic maps • Saskatchewan topographic maps • Manitoba topographic maps Mapping by wetland type can provide some insight related to geology and soils (peatland vs mineral soils) Local knowledge and experience important
Example of application	Devito et al. (2005) in a study of hydrologic response units (HRUs) on the Boreal Plains found that while topographic measures may be convenient for defining catchments, topography does not tell the complete story in the Boreal Plains. In fact, based on their work in the Boreal Plains, Devito et al. (2005) developed a hierarchy of controls that should be followed to develop a conceptual framework to determine the dominance of specific components of the hydrologic cycle and to determine the scale of interaction that should be considered: a. climate; b. bedrock geology; c. surficial geology; d. soil type and depth; e. topography and drainage. This broader understanding of HRUs, beyond being defined primarily by topography, has implications for forest management activities. Devito and Spafford (2005) describe how this information can be used to maximize harvesting and hauling efficiencies such as: prioritizing winter operations, avoiding non-frozen conditions where feasible, and applying best practices for resource roads and harvest.
Objective(s) and principle(s) supported	Supports all objectives Supports all principles

Location of planned access and harvest activities in relation to wetlands and the following:

- key attributes and functions of different wetland types (e.g., water flow, deep organic vs. shallow organic soils)
- position of wetlands in the watershed
- wetland connectivity

<table>
<tr><td>Description/ Rationale:</td><td>Considering key wetland attributes and functions by type, wetland position in the watershed, and wetland connectivity can assist with wetland stewardship planning in several ways. Different boreal wetland types have different ecological characteristics. Basic wetland classification skills and an understanding of key wetland characteristics will help forestry professionals make decisions to minimize potential adverse effects on wetlands. For example:
Bogs and fens tend to have deeper, saturated organic soils with poor bearing capacity. These wetland types will require additional consideration when planning the design and location of infrastructure, choosing equipment, and timing forest management activities.
Water movement at or below the surface in fens (lateral) and swamps (lateral or vertical) can cause issues during access, harvest, and silviculture activities.
Crossing shallow open water and marsh wetlands requires frozen ground or specialized crossing structures (e.g., bridges).</td></tr>
<tr><td>Supporting information</td><td>For supporting information on legal and certification requirements and literature on application or effectiveness, refer to Appendix 6, section 2.2.</td></tr>
<tr><td>Application</td><td>Several tools and approaches can be used to collect information on key attributes and functions and can help with decision making (additional information on these tools can be found later in this chapter). Tools include:
Wetland inventory maps with wetlands classified to the five major classes or in greater detail (e.g., the EWC’s 19 minor classes)
Hydrography maps for landscape position
LiDAR or tools developed using LiDAR (e.g., wet areas mapping) for understanding connectivity
Mapping wetlands within the context of watershed boundaries can provide insight into water yield and fluctuations. This information is important to consider when planning wetland crossing locations.
Anticipate increased water yield and water level fluctuation lower in the watershed that will require accommodation when designing and constructing crossings.
Understanding whether wetlands are isolated or connected will provide valuable insight into anticipated water yield. Connected wetlands typically have greater water movement and potentially greater water fluctuations than isolated wetlands
Consider wetland connectivity when developing planned road corridors and harvest block locations</td></tr>
</table>

	Staff and contractor training to raise awareness of the diversity of wetland types they may encounter and how the ecological characteristics of different wetland types can affect their work.
Example of application	Factors such as key wetland attributes, position in the watershed, and wetland connectivity can be underestimated. As a result, there may be challenges with road construction, maintenance, safety, or additional economic costs. **Algar Lake, Millar Western Forest Products Ltd.** In late December 2006 Millar Western Forest Products Ltd. installed a wetland crossing at Algar Lake (Figure 20). Initially, the river and crossing location were frozen over, with an ice bridge seeming to be an appropriate choice. Despite seasonably cold temperatures for the time of year, the river thawed and began to flow. At that point, it was believed that the crossing could be salvaged with the addition of a culvert to address the water flow, however it turned out that the original plan to put in place an ice bridge with the supplemental culvert was not sufficient for the flowing conditions (Figures 21 and 22). As an alternative solution, a steel bridge was brought in to adjust for the site conditions which was ultimately successful. (Figure 23, 24 and 25). Understanding the wetland types present at this crossing location would have helped identify potential challenges before going in the field and helped inform decision making about the type of structure to use (e.g., icebridge vs. steel bridge) for the situation.  ***Figure 20***. Location of wetland crossing (photo credit Millar Western)   ***Figures 21 and 22.*** Snow bridge and culvert (photo credit Millar Western

	  ***Figures 23 and 24.*** transporting and placing the bridge (photo credit Millar Western)  ***Figure 25.*** Bridge in place (photo credit Millar Western)
Objective(s) and Principle(s) supported	Supports all objectives, particularly: Avoid or minimize blockage or disruption of wetland surface and subsurface water flow Supports all principles, particularly: maintain hydrologic connectivity

Locate wetland crossings to minimize disturbance:

Description/ Rationale	A carefully chosen crossing location can minimize potential adverse effects to wetlands. Crossing location can also decrease the likelihood of road degradation over time and could therefore help reduce maintenance and/ or restoration costs.
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 2.3
Application	When crossing wetlands cannot be avoided, often the narrowest point within a wetland offers the least amount of habitat disturbance and loss (e.g., Yukon Chamber of Mines 2010). However, other factors such as slope, soil stability, hydrologic flow, and wildlife features (e.g., bird nests, fish habitat) should also be considered when choosing wetland crossing locations. For example, crossing at the narrowest point of slow flowing wetlands may result in "pinch points" where surface and subsurface flow maybe concentrated (Ducks Unlimited Canada 2014, Partington et al. 2016). Narrow wetland crossings could become problem areas for water flow blockage because of storm water debris or beavers.
Example of application	Louisiana Pacific Ltd. (LP) uses information about wetlands to plan harvest areas and harvest area access to minimize wetland crossings and potential adverse effects to wetlands. LP's management areas in western Manitoba are mosaics of wetlands and uplands. Ecosystem Based Management started with only the forested ecosystems, but now LP includes both upland and wetland ecosystems in their 20 Year Forest Management Plan. For example, LP used the DUC Enhanced Wetland Classification (EWC) along with aerial imagery to plan the route and construction techniques for an access road going between an existing road and a proposed harvest block. The EWC was used to identify wetland location and type to find a route that minimized wetland crossings. LP conducted field scouting to confirm the best location and reviewed aerial imagery to understand potential seasonal fluctuations in water levels. LP then used this information to inform the time of year for construction and the techniques and materials used. The result was an access road that minimized wetland crossings and was designed to accomodate the wetland types crossed.
Objective(s) and principle(s) supported	Supports all objectives, particularly: maintain structure and function of riparian vegetation and aquatic systems Supports all principles

Consider the wetland type when choosing the wetland crossing

Description/ rationale	When planning a wetland crossing, identifying wetland type can provide insight into ecological characteristics such as permanency, amount and type of water flow, and soil characteristics. Wetland type and location are important to consider as part of the crossing design. The following information can help inform this process: • Wetland types present and their ecological and hydrological characteristics • Maps of wetland distribution • Location of a crossing within a watershed • Connectivity of the wetland(s) being crossed to other wetlands • Predicted water flow
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 2.4.
Application	To assist with predicting water flow, wetlands can be grouped into four categories that describe water flow under average climatic conditions: 1. Stagnant – no to gradual flow 2. Moving – slow lateral flow 3. Moving – seasonally fluctuating 4. Inundated/Flooded Refer to Appendix 7 for additional information on wetland flow types. Tools described later in this Chapter can be applied.
Example of application	FPInnovations documented the construction of a section of resource road built across a treed bog and established a 700m section for long term monitoring. The road is in the Alberta-Pacific Forest Industries' Forest Management Agreement Area in northeast Alberta. Long term monitoring included road settlement and road and culvert performance. The wetland crossing was constructed by removing small black spruce trees, shrubs, and other vegetation to a width of 45m. Equipment used was light enough to be used on frozen ground without breaking through the peat. The road was filled with clay-based soil/ fill material from a nearby borrow pit and granular material sourced from higher ground located at the two approaches to the wetland. Culverts were 18 m long (2x9 m joined by couplers), placed directly on the intact peat layer, and covered with fill material (1-2 m). Four culverts were spaced across the crossing with some consideration to where surface water had accumulated. Preliminary results showed some settlement, particularly on the side of the road with loaded truck traffic. The culvert with the greatest settlement (culvert #4) was installed in an area with higher surface water levels and deeper fill heights over the culvert. A fifth culvert was added to the wetland crossing near culvert #4 to accommodate the additional flow in this area.
Objective(s) and principle(s) supported	Supports all objectives, particularly: avoid or minimize blockage or disruption of wetland surface and subsurface flow, maintain hydrologic connectivity

Schedule activities to occur during favorable weather conditions

Description/ rationale	When possible, schedule construction and operations in wetlands during winter months when the ground is frozen and less susceptible to rutting and compaction. Avoid scheduling activities during spring break up. When working in frozen conditions is not possible, work during dry conditions and avoid scheduling work during rainy periods or when soils are expected to be saturated from snowmelt. Working in wetlands when soils are dry helps reduce potential habitat degradation and may reduce route and site maintenance and reclamation costs.
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 2.5.
Applications	At the planning stage it is important to understand the scope of operations and what can be accomplished during favourable weather conditions. Identifying what activities may need to occur when the ground is not frozen will be important for identifying operational BMPs to minimize potential adverse effects to wetlands. This information can also be used to avoid higher risk wetlands during the times of year when safety risks are highest (i.e. spring break up).
Objective(s) and principle(s) supported	Objectives: • Avoid or minimize blockage or disruption of wetland surface and subsurface water flow • Avoid or minimize soil compaction • Avoid or minimize soil layer disturbance • Avoid or minimize increased run-off and erosion • Avoid sediment and other potential pollutants from entering the wetland Principles: Maintain wetland quality, maintain hydrologic processes, maintain hydrologic connectivity

Establish vegetated zones around wetlands

Description/ rationale	Where possible and appropriate, plan setbacks (vegetated zone where activities are limited or not allowed) to surround wetlands. Applying these zones around wetlands within harvest blocks could be considered an avoidance or minimization strategy depending on the setback width and the activities allowed within.
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 2.6.
Application	• Zone widths will largely depend on regulation and conservation goal • Most jurisdictions have no legal requirements for vegetated zones around wetlands. • Generally, forest managers apply "buffers" around isolated open water and marsh wetlands as they can be more easily identified and delineated. It can be more challenging to apply setbacks to vegetated wetlands and to wetland complexes as they are not easily identified and can be difficult to delineate. • Typically, setbacks around fens, bogs, and swamps have not been applied although there is evidence that they are important to maintaining ecological functions.
Objective(s) and principle(s) supported	Supports all objectives Supports all principles

Establish storage sites and recovery plans for petroleum products and other pollutants

Description/ Rationale	While there are potential negative effects of pollutants entering a wetland, forest managers engage in few high risk activities in this area. The most likely risk is petroleum products from vehicles and equipment. Planning ahead to minimize risk can include: establishing storage sites, identifying preventative measures to stop pollutants from entering wetlands, and developing spill response plans.
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 2.7.
Application	These plans could include: • Location of storage sites • Setbacks from wetlands for certain types of materials or certain activities where there is the potential for leaks or spills • Clean up and/ or recovery plans for different material types with potential to spill
Objective(s) and principle(s) supported	Objective(s): Prevent sediment and pollutants from entering the wetland Principle(s): Maintain wetland quality, maintain hydrologic processes

Minimize invasive species introduction and spread

Description/ Rationale	Managing the introduction and spread of invasive species is an important component of sustainable forest management. Invasive species have the potential to adversely affect wetlands as well as managed upland forests. Wetland invasive species generally alter wetland plants and animals, which can in turn affect wetland function including hydrologic processes (e.g., nutrient cycling). Preventing the introduction of invasive species into wetlands is the easiest way to minimize adverse effects. Once introduced, control of many species is challenging and may require significant cost. Developing a plan to minimize introduction and spread is an important planning consideration for wetland stewardship.
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 2.8.
Application	• Identify invasive species that are known to occur within the FMA and those with future invasive potential within the FMA. • Consider both aquatic and terrestrial invasive species. Aquatic invasive species, such as those identified in Chapter Five, pose less of a risk to forest resources, but are important to manage to achieve wetland stewardship objectives. • Companies may develop protocols (operational practice) to monitor and track known invasive species. This information can be used at the planning stage to identify risks and approaches to minimizing risks. • Consider the relevant provincial or territorial legislation and responsibilities under that legislation. For example, in Alberta invasive species under legislative control are listed as noxious or prohibited noxious, with different requirements for the two groups.
Objective(s) and principle(s) supported	Objective(s): Avoid or minimize invasive species introduction and/ or spread Principle(s): Maintain wetland quality

Enhancing knowledge and awareness

The following are planning considerations that can be applied by forest companies to enhance knowledge and awareness to promote positive outcomes for wetlands through wetland avoidance and minimization.

Targeted off highway vehicle recreation

Description/ Rationale	Traversing wetlands can be an entertaining challenge for recreational off highway vehicle (OHV) users. However, OHV activity can significantly damage wetland soils, vegetation, and water quality. Forest managers can use wetland inventory maps to help plan to avoid/minimize OHV user access and use of wetlands.
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 3.1.
Application	• Use wetland inventory maps to work with local recreation associations to plan and create new trails in areas where wetland density is low. • Where wetlands have been degraded by off highway vehicle use, explore options to reroute existing trails through wetlands to non-sensitive upland sites to minimize further wetland degradation and promote recovery. • Wetland degradation from off highway vehicle trails can be identified remotely using wetland inventory maps and/or satellite imagery. • Consider using avoidance considerations described in Tables 6, 7, and 8 to help prioritize wetlands that are expected to be most sensitive to off highway vehicle use for avoidance and recovery. • Access barriers, signage, and education materials can help prevent access and use of wetlands by off highway vehicle users, consider these proactive approaches where possible. • Develop a plan to monitor and evaluate the effectiveness of minimization activities (e.g., putting up signage or barriers).
Example of application	Minesing Wetlands in southern Ontario is a 7,000-hectare site that provide habitat for a large variety of flora and fauna. The wetlands are part of a land holding of the Nottawasaga Valley Conservation Authority (NVCA) and other government and private landowners. Vehicle access on NVCA lands in the wetlands is a prohibited and damaging activity, yet with little in the way of physical or visual barriers on access point and limited enforcement options and resources, mud truck and all-terrain vehicle operators caused significant damage to sensitive areas within the wetlands. The Friends of Minesing Wetlands used several strategies to respond: • Installed seven vehicle access barriers at key access points • Installed signs at key access points • Circulated fact sheets on motorized vehicle damage in wetlands Learn more about the Minesing Wetlands vehicle access barriers and signage project

Objective(s) and principle(s) supported	Supports all objectives Supports all principles

Reclamation

Description/ Rationale	• Requirements for reclaiming temporary features (e.g., temporary roads). • Wetlands are often sensitive habitats and may not recover naturally following removal of the disturbance. As a result, foresters may have to assist with the recovery of damaged wetlands. • Planning to reclaim wetlands can include identifying damaged areas, determining what functions need to be restored, determining best methods for reclaiming, implementing those methods and monitoring results. • Planning can help minimize the need and extent of wetland reclamation needed. For example, prioritizing wetlands that are challenging to reclaim (e.g., those with deep peat soils) for avoidance or using minimization practices at the construction stage, may improve reclamation outcomes and/ or reduce the amount of time and effort required to reclaim.
Supporting information	For supporting information on legal and/ or certification requirements and/ or literature on application or effectiveness, refer to Appendix 6, section 3.2.
Application	• Prioritize areas of highest importance – this may be based on social or ecological values, regulatory requirements, areas that are not recovering naturally, or other criteria. • Suspected damage can potentially be identified remotely using wetland inventory maps and/ or satellite imagery. • Linear features such as roads and trails (including winter roads) are areas where there may be visual evidence of damage to wetlands. These are areas that may be investigated remotely and/ or ground-truthed. • Other linear features, such as seismic lines, located in wetlands may not recover naturally. These are areas for potential improvement by forest companies by contributing to or participating in seismic line reclamation work (refer to supporting information in Appendix 6 3.2 for additional information on seismic line reclamation approaches). • Consider potential approaches through the lens of restoring site hydrology and topography, substrate chemistry, and vegetation. • Plan to monitor and evaluate effectiveness of reclamation approaches that are applied.
Example of application	Wetland road crossings, for example, may not recover naturally, and may require additional inputs. This is particularly true for peatland road crossings which may need specific conditions to return the site to a peat forming system. In areas of peat harvesting, three main criteria are generally required to return a site to a peat forming system, these include re-establishing: • Hydrology and topography • Substrate chemistry • Vegetation

	This may require re-contouring, levelling, bringing in substrate, saving substrate from earlier activities, re-vegetation by planting or peatland specific techniques such as the moss layer transfer. The NAIT Boreal Research Institute demonstrated the reclamation of a wood chip road located in a wooded fen near Peace River, Alberta (NAIT 2016). In this case they had to: • Level the reclaimed surface with surrounding fen hollows to reintegrate site hydrology with the surrounding area. • Buried woodchips became part of the peat and additional changes to site chemistry were not anticipated. • Local seed sources from surrounding fen were anticipated to naturally re-vegetate the site, nursery stock of black spruce and tamarack seedlings were planted and additional sedges and shrubs could be transplanted.
Objective(s) and principle(s) supported	Supports all principles Does not support objectives as this planning consideration is about reclaiming affected areas and not about avoiding or minimizing adverse effects

Education and training

Introductory wetlands training

Description/ Rationale	Understanding wetlands is pre-requisite for wetland stewardship. Without an understanding of the importance, types, and functions of wetlands it is impossible for those working on the landscape to act as stewards of these habitats. Wetlands training can: • Provide insight into the environmental, social, and economic values wetlands provide. • Build an awareness of why to avoid, minimize, or improve wetlands. • Improve awareness and understanding of how wetlands may affect forest operations and economic reasons for avoiding, minimizing, and improving wetlands. • Improve awareness and understanding of best management practices (BMPs) for avoiding and minimizing potential adverse effects to wetlands including – what are BMPs, how they can help, what needs to be considered when choosing a practice (e.g., wetland type, climate, and season).
Application	Wetlands training can come in a variety of formats, in the field, course-based, online or a combination of multiple approaches. Availability and applicability of training varies based on location and focus. Wetlands training includes: • DUC provides wetlands training to companies that can be tailored to specific company needs • Companies may develop their own wetland training programs (e.g., Louisiana Pacific has a wetlands training program for staff) • Universities and colleges may offer wetlands training through their continuing education departments, these courses are unlikely to be industry specific but may introduce wetland basics relevant to the area they are offered.
Example of application	DUC staff conducted wetland training with Louisiana Pacific Canada Ltd. staff in Swan River Manitoba. The training consisted of classroom and field components and was attended by a range of staff, from planners to equipment operators. The training covered an introduction to boreal wetlands including wetland types, functions, and ecosystem services. The field component provided an opportunity for students to learn and practice wetland identification using vegetation, soil, and hydrology indicators. Students and instructors also discussed challenges relating to wetlands that they encountered in their jobs.
Objective(s) and principle(s) supported	Supports all objectives Supports all principles

Best Management Practices training

Description/ Rationale	Learning about practices that can be applied to avoid or minimize adverse effects to wetlands from forest industry activities can help improve outcomes for wetlands. Building on an introductory understanding of wetlands acquired from wetlands training or similar, BMP training can provide information and guidance about how to apply knowledge of wetland types when carrying out forest industry activities. For example, information about hydrologic characteristics of various wetland types can be applied to road building. This type of training can increase awareness of considerations to minimize adverse effects and practices that may be applied to do so.
Application	• In 2016 FPInnovations (FPI) and DUC released the *Resource roads and wetlands: A guide for planning, construction and maintenance.* Following the release, FPI and DUC hosted a series of workshops in Alberta, Saskatchewan, Manitoba, and Quebec. These workshops provided an opportunity to share wetland and resource road BMP information from the guide with practitioners in a field setting. • In 2015 DUC and AlPac staff visited a number of wetland road crossings on the AlPac FMA. Using tools, such as DUC's Enhanced Wetland Classification and high-resolution imagery, potential challenge areas were identified ahead of time. During the visit the group identified areas where there was evidence of impaired hydrology, identified wetland types at a range of crossings, and discussed how this information could inform future maintenance or road building. • Consider carrying out internal field or classroom training to discuss challenges relating to working in and around wetlands and potential solutions. Consider bringing in outside expertise where appropriate.
Example of application	Ducks Unlimited Canada in collaboration with FPInnovations hosted several workshops in Alberta, Saskatchewan and Quebec to discuss and apply the information in the *Resource road and wetlands: a guide for planning, construction and maintenance*. The workshops were targeted towards forest industry planning and operational staff. DUC brought expertise in wetland identification and ecology and FPInnovations brought expertise in resource road engineering for a variety of conditions. Together the instructors discussed the challenges and important considerations for building resource roads in wetlands, how different wetland types should be incorporated into the planning and design process, and different potential construction techniques that can be used to maintain flow across wetlands. The workshops received very positive feedback and attendees learned things about wetlands and roads that could be applied to their job.
Objective(s) and principle(s) supported	Supports all objectives Supports all principles

Tools

Forest Vegetation Inventories (interpreting existing forest inventories)

In the absence of the planning tools mentioned below, forest vegetation inventories can be used to help map wetland locations within forest management areas. Each provincial government establishes their own vegetation inventory standard that requires the identification of the type, extent and condition of vegetation mapped (e.g., British Columbia, Alberta Vegetation Inventory, Saskatchewan Forest Vegetation Inventory, Manitoba Forest Land Inventory). These inventories are photo based with some ground verification, and typically developed for forestry with an emphasis on commercial forest stands. However, inventories are becoming increasingly comprehensive and capture a broader range of vegetation communities including wetlands (e.g., the B.C. Vegetation Resource Inventory). The level of detail of non-commercial forest contained in these inventories varies by provincial/territorial jurisdiction and also within jurisdictions (e.g., Manitoba). Generally, wetlands are considered as "non-contributing", "non-productive", and sometimes "non-vegetated" within these inventories. The polygons within these inventories are typically interpreted with basic attributes. Specific wetland habitat type and/ or function is not implied, but basic attributes can be utilized to identify wet areas.

Hybrid Wetland Layer

There are many wetland and waterfowl maps across the western boreal forest including Ducks Unlimited Canada's (DUC) Enhanced Wetland Classification (EWC), that provide detailed wetland classification; however, the EWC does not cover the large spatial extent of the Canadian Boreal forest. Therefore, the Hybrid Wetland Layer (HWI), created by the Western Boreal Program (WBP) geospatial services group, is a merged product that fills in the data gaps across Canada. This allows DUC and other users to claim and report on wetland and upland acres conserved and estimate waterfowl habitat. The HWL is a Canada wide land-based wetland map that categorizes the landscape into three general classes of wetland, upland and water. For areas where no EWC coverage was available, two data sources were used: 1) Earth Observation for Sustainable Development (EOSD), a product derived from the Canadian Forest Service (CFS) with collaboration from the Canadian Space Agency (CSA), and 2) CanVec, a digital cartographical reference product managed by Natural Resources Canada (NRC). It is recommended that the HWL is to be used for regional and national use of open water and general wetland/upland cover.

Jones, N. 2011. Hybrid Wetland Layer. User Guide. Version 2.1.1. Ducks Unlimited Canada.

Canadian Wetland Inventory (Ducks Unlimited Canada 2016)

The Canadian Wetland Inventory (CWI) is a national approach to establish a consistent framework to map wetlands to build Canada's capacity to respond to local, regional, national and international needs. The CWI encourages consistent interpretations by communities of interest through a common data structure and classification system. Based on The Canadian Wetland Classification System, the Canadian Wetland Inventory data model divides wetlands into shallow open water, marsh, swamp, fen, and bog.

The CWI Progress Map displays wetland areas across Canada that have been mapped to date. It's used to assess future wetland loss, degradation and restoration. This interactive map displays CWI-compatible wetland inventory areas that have been completed or are in progress across Canada. This application also visualizes detailed wetland polygons and information for certain areas where wetland inventory data have been made available. The map has been compiled to make wetland information readily available for a broad range of users. Source and partnership information for the various wetland inventory datasets have been provided within the map application.

DUC's Enhanced Wetland Classification

The Enhanced Wetland Classification (EWC) is a detailed, 19-class wetland classification of the Canadian Boreal Forest. This detail wetland classification allows DUC to focus their conservation efforts to conserve critical waterfowl habitat, assess industrial activities, and provide inputs to scientific research and modelling efforts to support international, national, and regional wetland mapping programs.

The EWC data model divides the Canadian Wetland Classification System (CWCS) 5 major classes into the EWC 19-class system: 1) Shallow Open Water – Aquatic Bed, Mudflats, and Open water; 2) Marsh – Emergent, and Meadow Marsh; 3) Swamp - Tamarack, Conifer, Hardwood, Mixedwood, and Shrub Swamp; 4) Fen – Poor and Rich Treed, Shrubby, and Graminoid Fen; and 5) Bog – Treed Shrubby and Open Bog.

The breakdown of the EWC data model is based on the most important underlying factors forming wetlands, including: water table depth (hydrology), water flow (hydrodynamics), and nutrient availability. Each wetland class has a set of environmental conditions, which dictates the vegetation indicator species; and therefore dictates the wetland class. The classification scheme of the EWC allows inferred products to be developed that map the distribution of hydrodynamics, soil moisture, and relative nutrient based on wetland classes.

Smith, K. B., C. E. Smith, S. F. Forest, and A. J. Richard. 2007b. A Field Guide to the Wetlands of the Boreal Plains Ecozone of Canada. Ducks Unlimited Canada, Western Boreal Office: Edmonton, Alberta. 98 pp.

Alberta Merged Wetland Inventory

The Alberta Merged Wetland Inventory (AMWI) spatially depicts wetlands within the province of Alberta, Canada from the period of 1998 to 2015. This inventory is classified to the five major wetland classes of the Canadian Wetland Classification System (CWCS), including bog, fen, marsh, swamp and shallow open water (although shallow open water includes all open water). This information is used to evaluate the status of wetlands at a regional level, however it is not intended to replace local or site-specific information The AMWI is made up of 33 individual wetland inventory components which have been developed utilizing differently types of source data from different years, different data capture specifications and different classification systems. As a result, there is high variability in terms of level of detail and accuracy within the AMWI. Three classification systems have been used to develop the 33 components of the AMWI, these include: 1) Ducks Unlimited Canada's (DUC) 19 detailed wetland class Enhanced Wetland Classification (EWC) system, 2) SPOT Grassland Vegetation Inventory (GVI) Lentic Classification which classifies wetlands based on type and permanence, and 3) use of high-resolution stereo models to capture and classify wetlands to a minimum mapping unit (MMU) of 0.02 and 0.1 ha. Currently, the AMWI does not cover the entire province, as there are data gaps within Wood Buffalo National Park and the eastern slopes of the province.

Alberta Environment and Parks, Government of Alberta. 2017. Alberta Merged Wetland Inventory. Available at: http://aep.alberta.ca/forms-maps-services/maps/resource-data-product-catalogue/biophysical.aspx.

Wet Areas Mapping

The Alberta Wet Areas Mapping (WAM) GIS-based product is a data collection depicting wet areas derived from one-meter spatial resolution digital terrain models, which were interpolated from LiDAR point cloud ground returns. The purpose of this dataset is to provide forest management with high-resolution flow-channel and wet-area maps for forest planning and operations. WAM data estimate depth to water, or the distance between the bare ground surface derived from the LiDAR models and a cartographically referend water table surface. This data has been used to inform users of hydrological risks due to vulnerability, such as areas with ephemeral to intermittent flows. It can also serve as a support tool for locating and/or delineating road-stream crossings and wetlands.

Alberta Agriculture and Forestry, Government of Alberta. 2016. Wet Areas Mapping Depth to Water. Available at: http://aep.alberta.ca/forms-maps-services/maps/resource-data-product-catalogue/hydrological.aspx

Murphy, P. N., Ogilvie, J., Castonguay, M., Zhang, C. F., Meng, F. R., & Arp, P. A. (2008). Improving forest operations planning through high-resolution flow-channel and wet-areas mapping. The Forestry Chronicle, 84(4), 568-574.

Field Guides

MacKenzie W. H. and J. R. Moran. 2004 Wetlands of British Columbia: A Guide to Identification. Res. Br., B.C. Min. For., Victoria, B.C. Land Manage. Handb. No. 52

Ducks Unlimited Canada. 2014. Field Guide of Boreal Wetland Classes in the Boreal Plains Ecozone of Canada. Edmonton, AB.

McLaughlan, M. S., R. A Wright,and R. D. Jiricka. 2010. Field guide to the ecosites of Saskatchewan's provincial forests. Saskatchewan Ministry of Environment, Forest Service. Prince Albert.

Ecological Land Classification field manual – operational draft, April 20th 2009 - Great Lakes - St. Lawrence. Ecological Land Classification Working Group, Ontario.

Ontario Ministry of Natural Resources. 2009b. Ecological Land Classification field manual – operational draft, April 20th 2009 - Boreal. Ecological Land Classification Working Group, Ontario.

New Brunswick Department of Natural Resources, Fish and Wildlife Branch. 2006. New Brunswick Wetland Classification for 2003-2012 photo cycle.

Nova Scotia Department of Natural Resources. 2004. Wetland Classification and Vegetation Typing.

Chapter Six Summary

- Key decisions in wetland stewardship occur at the planning phase. In this Chapter we presented a range of planning considerations that can be applied to avoid or minimize adverse effects to wetlands. Some of these practices may already be widely applied, while others are not yet a part of standard practice.
- Avoidance is the first stage in many environmental mitigation strategies and/ or policies and can be achieved through planning by determining the abundance, type and location of wetlands within the area of interest and then choosing locations for access and timber harvesting that are not in or near wetlands. Avoidance practices described in this document include:
  - Map the distribution of wetlands on the landscape by type
  - Avoid new disturbances to wetlands by participating in integrated land management planning
  - Avoid new disturbances to wetlands by locating new infrastructure near or on existing disturbances and by planning access routes to accommodate future development needs
  - Prioritize avoidance
- Avoidance is difficult to achieve in the boreal forest due to the high density and distribution of wetlands. As a result, forest managers should plan to minimize potential harmful effects of forest operations on wetlands. Minimization practices described in this document include:
  - Consider timing, location and equipment when working in or near wetlands in relation to the following: climate, bedrock and surficial geology, soils, and topography and drainage network
  - Consider the location of planned access, harvest, and renewal activities in relation to wetlands and the following: key attributes and flow characteristics, position of wetland in the watershed, and wetland connectivity
  - Locate wetland crossings to minimize disturbance
  - Consider the wetland type when choosing the wetland crossing
  - Schedule activities to occur during favourable weather conditions (e.g., winter operations, shutting down operations during spring runoff or heavy rain events)
  - Establish buffer strips during harvesting
  - Establish storage sites and recovery plans for petroleum products and other pollutants
  - Minimize invasive species introductions and spread
- There are a wide range of tools available that can assist with the application of the avoidance and minimization considerations. These include forest vegetation inventories, the hybrid wetland layer, the Canadian wetland inventory, DUC's Enhanced Wetland

Chapter Seven: Gaps and Recommendations

Our understanding of boreal wetlands, potential adverse effects, and practices to avoid and minimize adverse effects are growing fields. This report is based on the best available information, but we recognize that there are several knowledge gaps. As more information becomes available, recommendations made in this report may change. In this Chapter we summarize some key gaps in our understanding of boreal wetland stewardship and forest management and identify high level approaches to filling those gaps. Knowledge of topics such as boreal wetland succession, carbon dynamics, hydrologic connectivity, and others identified in Table 9 are important for understanding potential adverse effects to wetlands and identifying effective avoidance and minimization approaches.

Table 9. Summary of gaps and recommendations to fill gaps relating to wetland stewardship and forest management. Supporting literature around the current state of knowledge for these topics can be found in Appendix 7.

Topic	Gaps	Filling the gaps
Successional dynamics over space and time given historical landscape conditions and projected conditions	Successional trajectory for all wetland types, particularly peatlands. Including: • Controls on successional trajectory (e.g., effects of wet/ dry periods, changes to hydrology). • How to establish a peat forming system, whether a peat forming system becomes a peatland. • Effect of disturbance (e.g., fire, flood, disease) on wetland succession. • Effect of disturbance suppression (e.g., fire suppression) on wetland succession. • Wetland succession is known to move both forward and backward, how to predict next or future steps in wetland successional trajectory.	• Some research is currently taking place, stay up to date on outcomes of this work • Identify opportunities for potential future research • Where opportunities exist, consider monitoring successional trajectory of wetlands
Wetlands and forest fire	Effects of fire on wetlands, particularly peatlands. Including: • Wetland recovery following fire. • Potential effects of climate change on wildfire occurrence, frequency, severity, and wetland recovery. • Controls on peat burn severity and recovery (e.g., groundwater connectivity, type of vegetation, water table level). • How to mitigate wildfire carbon loss through restoration.	• There are several research studies currently taking place on the topic of forest fire and boreal wetlands, stay up to date on outcomes of this work. • Identify and engage in opportunities for potential future research.

	• Effects of fire suppression on wetlands. • Potential of wetlands to influence wildfire spread and severity of surrounding uplands. • Carbon source and sink dynamics of peatlands following fire.	• Work towards a better understanding of the role of wetlands in fire and natural disturbance models (e.g., role of wetlands in LandWeb).
Vegetation regeneration success – e.g., road crossing reclamation	Requirements for vegetation regeneration in wetlands, particularly peatlands. Including: • Conditions needed for natural wetland vegetation regeneration, including establishment of peat forming species. • Effectiveness of wetland vegetation recovery approaches (e.g., planting, moss layer transfer). • Effectiveness of natural and active wetland vegetation recovery for different wetland types. • Controls on wetland vegetation regeneration/ establishment success (e.g., microtopography, hydrology). • Requirements and approaches for establishing trees in regenerating wetlands.	Where opportunities exist: • Monitor regeneration success and track conditions that may contribute to success or failure (e.g., site conditions, techniques, timing). • Conduct pilot studies to test and monitor potential practices. • Support or partner in research studying wetland vegetation regeneration – e.g., work reclaiming roads • Keep current on literature and consider trialing new regeneration approaches that may be effective for your location.
Wetland hydrologic connectivity	Water movement within wetlands, between wetlands, and between wetlands and uplands, including: • Understanding how boreal wetlands are connected at landscape and local scales. • Role played by wetlands, particularly peatlands, in transmitting water across the landscape (e.g., conditions, amount). • Subsurface water connections between wetlands and uplands and role of these connections in supporting upland forest productivity.	Where feasible and opportunities exist: • Use maps, tools and wetland knowledge to understand the local and landscape hydrology of the area of interest. • Identify position within the catchment. • Monitor water movement at road wetland crossings, when putting in a new crossing consider

	• Effects of altering natural hydrology, and ability to predict potential effects. • Influence of catchment position on effects of hydrologic impairment.	measuring hydrology and flow before installation and monitoring these parameters after installation. • Consider collaborating with other groups (i.e. research, industry associations) to better understand water movement including: - direction of flow - amount of flow - seasonal/ climatic controls • Share examples of successes at maintaining natural wetland hydrology and failures in impairing natural wetland hydrology.
Wetland hydrologic processes	• Effects of disturbance (e.g., fire, flood, harvest, insects/ disease) on boreal hydrologic processes. • Effects of hydrology on decomposition pathways. • Effects of hydrology on primary productivity.	• Keep current on literature relating to hydrologic processes in Canada's boreal wetlands (e.g. Mertens 2018).
Wetland greenhouse gas (GHG) dynamics	• Effect of climate change on wetland GHG emissions and carbon sequestration. • Effect of wetland loss and functional impairment (e.g., impaired hydrology) on wetland GHG emissions. • Controls on wetland GHG emissions (e.g., water table level).	Where opportunities exist: • Consider measuring GHG emissions at wetland road crossings and/ or collaborating with others (e.g., research groups, industry associations) to study effects of crossings on emissions.
Wetland carbon storage	• Landscape level estimates of carbon storage in wetlands, particularly peatlands, are lacking as a result of poor data availability, including:	• Consider supporting carbon mapping efforts • If measuring peat depths for as part of

	- Peat depth - Bulk density - Carbon accumulation • Understanding how carbon is stored in wetland, particularly peatland, soils. • Effect of forest management activities (e.g., road construction, in some areas harvest) on carbon storage. • Controls on what is a carbon sink vs. carbon source.	any activity, consider collecting data along standardized protocols and sharing data.
Relative value of wetland types	• Wetland valuation is subjective and there is no single set of factors that will universally determine wetland value. • Some work has been done to develop wetland valuation approaches (e.g., formula for the Alberta Wetland Policy). However, valuation is typically context specific (e.g., specific to a regulatory or policy need, a certification, or a geographic area) and little work has been done to assess valuation approaches.	• Proceed with caution if planning to value wetlands. Valuation is subjective and there is no single set of factors that will be able to tell you what wetlands are more valuable than others. • There may be future opportunities to assess valuation approaches. • Table 6 in Chapter Six describes wetland attributes to consider when valuing boreal wetlands
Effectiveness of minimization strategies	Many practices, including those described in this document, are not rigorously tested and are instead recommended based on primarily anecdotal evidence, field trials, or in some cases more formal evidence of effectiveness. As such, the effectiveness of many minimization strategies is a knowledge gap.	• When applying practices, consider developing monitoring strategies to assess the effectiveness of the practice.

Literature Cited

Agriculture and Agri-Food Canada (AAFC). 2007. Managing Wet Soils. Agriculture and Agri-Food Canada. Ottawa, Ontario.

Alberta Agriculture and Forestry, Government of Alberta. 2016. Wet Areas Mapping Depth to Water. Available at: http://aep.alberta.ca/forms-maps-services/maps/resource-data-product-catalogue/hydrological.aspx

Alberta Environment and Parks, Government of Alberta. 2017. Alberta Merged Wetland Inventory. Available at: http://aep.alberta.ca/forms-maps-services/maps/resource-data-product-catalogue/biophysical.aspx.

Alberta Environment and Sustainable Resource Development (AESRD). 2005. Alberta Vegetation Inventory Interpretation Standards. Resource Information Management Branch, Edmonton, Alberta.

Alberta Environment and Sustainable Resource Development (AESRD). 2006. Alberta Forest Management Planning Standard. Public Lands and Forests Division, Forest Management Branch, Edmonton, Alberta.

Alberta Environment and Sustainable Resource Development (AESRD). 2012. Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal. Forestry Division, Forest Management Branch, Edmonton, Alberta.

Alberta Environment and Sustainable Resource Development (AESRD). 2013. Alberta Wetland Policy.

Alberta Environment and Sustainable Resource Development (AESRD). 2015. Alberta Wetland Classification System. Water Policy Branch, Policy Division, Edmonton, Alberta.

Alberta Pacific Forest Industries Inc. Integrated Landscape Services. Accessed March 22, 2017 <https://alpac.ca/forest-sustainability/integrated-landscape-services >

Alberta Wood Products. 2017. Black Spruce. Accessed March 22 2017 <http://www.albertawoodproducts.ca/species/black-spruce/>

Anielski, M., and S. Wilson. Counting Canada's natural capital: assessing the real value of Canada's boreal ecosystems. Ottawa: Canadian Boreal Initiative; 2009

Batey, T. and D.C. McKenzie. 2006. Soil compaction: Identification directly in the field. *Soil use and Management*. 22: 123-131.

Bauer, I., Bhatti, J.S., Cash, K.J., Tarnocai, C., and Robinson, S.D. 2005. Developing statistical models to estimate the carbon density of organic soils. *Canadian Journal of Soil Science.* 86: 295-304.

British Columbia Ministry of Environment. 2014a. Environmental Mitigation Policy. <http://www.env.gov.bc.ca/emop/docs/EM_Policy_May13_2014.pdf>

British Columbia Ministry of Environment. 2014b. Procedures for mitigating impacts on environmental values (Environmental mitigation procedures). Environmental Sustainability and Strategic Policy Division, Ecosystems Branch. Victoria, British Columbia.

Brown, M., & Dinsmore, J. J. (1986). Implications of marsh size and isolation for marsh bird management. The Journal of Wildlife Management, 392-397.

Canadian Association of Petroleum Producers. 2004. Evolving Approaches to Minimize the Footprint of the Canadian Oil and Natural Gas Industry. Accessed March 22, 2017 <https://salmoconsulting.files.wordpress.com/2012/11/evolving-approaches-to-minimize-the-footprint-of-the-canadian-oil-and-natural-gas-industry.pdf >

Canadian Standards Association (CSA). 2016. CAN/CSA-Z809-16 – Sustainable forest management. CSA Group. Toronto, Ontario.< http://shop.csa.ca/content/ebiz/shopcsa/resources/documents/codes-and-standards/2424363.pdf>

Creed, I.F., Beall, F.D., Clair, T.A., Dillon, P.J., and R.H., Hesslein. 2008. Predicting export of dissolved organic carbon from forested catchments in glaciated landscapes with shallow soils. *Global Biogeochemical Cycles.* 22(4).

Creed, I., Sass, G., Beall, F., Buttle, J., Moore, D. and Donnelly, M. 2011. Hydrological principles for conservation of water resources within a changing forested landscape. Sustainable Forest Management Network, Edmonton, Alberta. 80pp.

Creed, I.F., and M. van Noordwijk (eds.). 2018. Forest and water on a changing planet: Vulnerability, adaptation and governance opportunities. A Global Assessment Report. IUfRO World Series Volume 38. Vienna. Pg. 192.

Culley, J.L.B., Dow, B.K., Presant, E.W., and A.J. Maclean. 1981. Impacts of installation of an oil pipeline on the productivity of Ontario cropland. LRRI Contribution No. 66. Research Branch, Agriculture Canada.

Daigle, P. 2010. A summary of the environmental impacts of roads, management responses, and research gaps: A literature review. *BC Journal of Ecosystems Management.* 10(3): 63-90.

DeJong Hughes, J., Moncrief, J., Voorhees, W.R., and J.B. Swan. 2001. Soil Compaction: Causes, effects, and control. University of Minnesota. Accessed January 19, 2017 < http://www.extension.umn.edu/agriculture/tillage/soil-compaction >

Devito, K., Creed, I., Gan, T., Mendoza, C., Petrone, R., Silins, U., and B. Smerdon. 2005. A framework for broad-scale classification of hydrologic response units on the Boreal Plain: is topography the last thing to consider? *Hydrological Processes.* 19: 1705-1714.

Devito, K., and M. Spafford. 2005. Boreal conservation: Hydrology and forestry in the Alberta-Pacific FMA area. Alberta, Canada. Pg. 64.

Devito, K. and C. Mendoza. 2006. Maintenance and dynamics of natural wetlands in western boreal forest: Synthesis of current understanding from the Utikuma Research Study Area. *Cumulative Environmental Management Association.* Alberta, Canada. Pg. 84.

Devito, K, Mendoza, C. and C. Qualizza. 2012. Conceptualizing water movement in the Boreal Plains: Implications for watershed reconstruction. Synthesis report prepared for the Canadian Oil Sands Network for Research and Development, Environmental and Reclamation Research Group. 164 p.

Devito, K.J., Mendoza, C., Petrone, R.M., Kettridge, N., and J.M. Waddington. 2016. Utikuma Region Study Area (URSA) – Part 1: Hydrogeological and ecohydrological studies (HEAD). *The Forestry Chronicle*. 92(1): 57-61.

Devito, K.J., Hokanson, K.J., Moore, P.A., Kettridge, N., Anderson, A.E., Chasmer, L., Hopkinson, C., Lukenbach, M.C., Mendoza, C.A., Morissette, J., Peters, D.L., Petrone, R.M., Silins, U., Smerdon, B., and J.M. Waddington. 2017. Landscape controls on long-term runoff in subhumid heterogeneous Boreal Plains catchment. *Hydrological Processes*. 31(15): 2737-2751.

Donnelly, M., Deviot, K.J., Mendoza, C., Petrone, R. and M. Spafford. 2016. Al-Pac Catchment Experiment (ACE). *The Forestry Chronicle*. 92(1): 23-26.

Dowling Jr. Hugh M. 2010. Sedimentation affection wetland soils and vegetation within the dog river watershed. Accessed February 13 2017 from <http://www.southalabama.edu/geography/fearn/480page/2010/10Dowling.pdf>

Ducks Unlimited Inc. 2005. Ducks Unlimited's International Conservation Plan: Meeting the annual life cycle needs of North America's waterfowl. Accessed March 22, 2017 from <http://www.ducks.org/media/Conservation/Conservation%20Plan/_documents/a_ICP2004%20final%208.05.pdf>

Ducks Unlimited Canada. 2014. Operational guide: Forest road wetland crossings Version 1.0. Ducks Unlimited Canada. Edmonton, Alberta.

Ducks Unlimited Canada. 2015. Field Guide - Boreal Wetland Classes in the Boreal Plains Ecozone of Canada. Version 1.2. ISBN 978-0-9812303-2-0

Ducks Unlimited Canada. 2016. Canadian Wetland Inventory. Accessed March 22, 2017 from <http://www.ducks.ca/initiatives/canadian-wetland-inventory/>

Elmqvist, T., Folke, C., Nystrom, M., Peterson, G, and Bengtsson, J. 2003. Response diversity, ecosystem change, and resilience. *Frontiers in Ecology and the Environment*. 1(9): 488-494.

Fairbairn, S.E., and J.J. Dinsmore. 2001. Local and landscape-level influences on wetland bird communities of the prairie pothole region of Iowa, USA. Wetlands 21: 41-47.

Fenner, N. and C. Freeman. 2011. Drought-induced carbon loss in peatlands. *Nature Geoscience.* 4: 895-900.

Ferone, J.M., and Devito, K.J. 2004. Shallow groundwater-surface water interactions in pond-peatland complexes along a Boreal Plains topographic gradient. *Journal of Hydrology*. 292: 75-95.

Foote, L. and Krogman, N. 2006. Wetlands in Canada's western boreal forest: Agents of change. *The Forestry Chronicle*. 82(6): 825-833.

Forest Stewardship Council (FSC). 2016. FSC Canada Standard: Public Consultation for National Management Standard: Draft 2. FSC-STD-CA-01-XXXX (D2-0) EN. FSC® International (FSC® F000205). Toronto, Ontario.

Forest Watershed Research Center. 2017. Wet Areas Mapping. Accessed March 22 2017 <http://watershed.for.unb.ca/research/wet-areas-mapping/ >

Forintek Canada Corp. 2006. Black Spruce. Facts on Wood Series https://www.albertacanada.com/files/albertacanada/AIS-BP_BlackSpruce.pdf

Fredrickson LH, Reid FA (1988) Waterfowl use of wetland complexes. Waterfowl management handbook – fish and wildlife leaflet 13.2.1. U.S. Fish and Wildlife Service, Washington, DC, USA

Gammonly, J.H. 2004. Wildlife of natural palustrine wetlands. Pages 130-153 in M.C. McKinstry, W.A. Hubert, and S.H. Anderson. Wetland and riparian areas of the intermountain west. University of Texas Press, Austin. 319pp.

Gardner, R. C., Bonells, M., Okuno, E., Zarama, J. M. 2012. Avoiding, mitigating, and compensating for loss and degradation of wetlands in national laws and policies. Ramsar Scientific and Technical Briefing Note no. 3. Gland, Switzerland: Ramsar Convention Secretariat

Gingras, B., Slattery, S., Smith, K. and Darveau, M. 2016. Boreal Wetlands of Canada and the United States of America. In: C.M. Finlayson et al. (eds). *The Wetland Book* p 1-23. Springer Netherlands.

Gleason, R.A., Euliss Jr., N.H., Hubbard, D.E., and W.G. Duffy. 2003. Effects of sediment load on emergence of aquatic invertebrates and plants from wetlands soil egg and seed banks. *Wetlands.* 23(1): 26-34

Government of Alberta. 2010. Describing the Integrated Land Management Approach. Integrated Land Management. Accessed on March 22 2017 <http://www.acr-alberta.com/Portals/0/projects/ilm/ilmwinwin.pdf>

Government of Alberta. 2012. Integrated Land Management Tools Compendium. O2 Planning + Design Inc., Calgary, Alberta.< http://aep.alberta.ca/lands-forests/integrated-land-management/documents/ILMToolsCompendium-Sep20-2012A.pdf >

Government of Alberta. 2013a. Alberta Wetland Policy. Accessed March 22, 2017 <http://aep.alberta.ca/water/programs-and-services/wetlands/documents/AlbertaWetlandPolicy-Sep2013.pdf >

Government of Alberta. 2013b. Enhanced Approval Process (EAP) Integrated Standards and Guidelines Version 2. Alberta Energy Regulator. Accessed March 22, 2017 <http://aep.alberta.ca/forms-maps-services/enhanced-approval-process/eap-manuals-guides/documents/EAP-IntegratedStandardsGuide-Dec01-2013.pdf >

Government of Alberta. 2015. ILM Success Stories. Accessed on March 22, 2017 <http://aep.alberta.ca/lands-forests/integrated-land-management/ilm-success-stories.aspx >

Government of Alberta. 2016. Alberta Wetland Policy Implementation. Alberta Environment and Parks. Accessed March 22, 2017 <http://aep.alberta.ca/water/programs-and-services/wetlands/alberta-wetland-policy-implementation.aspx >

Government of Alberta. 2017. Alberta Merged Wetland Inventory. Alberta Environment and Parks. Accessed March 22, 2017 <http://aep.alberta.ca/forms-maps-services/maps/resource-data-product-catalogue/biophysical.aspx>

Government of British Columbia. 2017. Biogeoclimatic Ecosystem Classification Program. Ministry of Forests and Range. Accessed November 29, 2017 < https://www.for.gov.bc.ca/hre/becweb/ >

Government of Canada. 1991. The Federal Policy on Wetland Conservation. Environment Canada. Ottawa, Ontario.

Grayson, W. 2016. Excavator salvaged from icy swamp in weeks long operation. Equipment World. Accessed January 17, 2016 from < http://www.equipmentworld.com/video-excavator-salvaged-from-icy-swamp-in-weeks-long-operation/ >

Halsey, L.A., Vitt, D.H., and D.O. Trew. 1997. Influence of peatlands on the acidity of lakes in northeastern Alberta, Canada. *Water, Air, and Soil Pollution.* 96: 17-38.

Hanson, A., Swanson, L., Ewing, D., Grabas, G., Meyer, S., Ross, L., Watmough, M., and J. Kirkby. 2008. Wetland Ecological Functions Assessment: An Overview of Approaches. Canadian Wildlife Service Technical Report Series No. 497. Atlantic Region. 59pp.

Henschel, C. and T. Gray. 2007. Forest carbon sequestration and avoided emissions: A background paper for the Canadian Boreal Initiative/Ivey Foundation. Forests and Climate Change Forum, October 15 – 17, 2007. Kananaskis, Alberta. Accessed on March 23, 2017 from < http://www.cef-cfr.ca/uploads/Reference/climate_forest.pdf>

Hillman, G. R. 1987. Improving wetlands for forestry in Canada. Northern Forestry Centre, Canadian Forestry Service, Edmonton, Alberta.

Hillman, G., and R. Rothwell. 2016. Spring creek representative and experimental watershed project. *The Forestry Chronicle.* 92(1): 43-46.

International Peat Society. 2008. Peatlands and Climate Change. ed.,M. Strack. Internal Peat Society. Jyväskylä, Finland 223pp. <http://www.peatsociety.org/sites/default/files/files/PeatlandsandClimateChangeBookIPS2008.pdf>

Ivey, J. L., and R. A. McBride. 1999. Delineating the zone of topsoil disturbance around buried utilities on agricultural land. *Land Degradation & Development.* 10: 531-544.

Johnstone, J.F., Stuart Chapin III, F., Hollingsworth, T.N., Mack, M.C., Romanovsky, V., and M. Turetsky. 2010. Fire, climate change, and forest resilience in interior Alaska. *Canadian Journal of Forest Research.* 40:1302-1312.

Jones, N. 2011. Hybrid Wetland Layer. User Guide. Version 2.1.1. Ducks Unlimited Canada.

Kozlowski, T.T. 1999. Soil compaction and growth of woody plants. *Scandinavian Journal of Forest Research*. 14(6): 596-619.

Lantagne, D.O., Hart, J.B., and C.R. Blinn. 1998. Soils and site productivity. In: Understanding forestry concepts: A forest ecology series for loggers, landowners, and foresters. Michigan State University Extension.

Lavoie, M., Pare, D., and Y. Bergeron. 2005. Impact of global change and forest management on carbon sequestration in northern forested peatlands. *Environmental Review*. 13: 199-240.

Lee, P., Smyth, C., and S. Boutin. 2004. Quantitative review of riparian buffer width guidelines from Canada and the United States. *Journal of Environmental Management.* 70(2): 165-180.

Locky, D.A. and S.E Bayley. 2007. Effects of logging in the southern boreal peatlands of Manitoba, Canada. *Canadian Journal of Forest Resources*. 37: 649-661.

Locky, D.A. 2009. Early stand-level assessment of forest harvesting in western boreal peatlands. Sustainable Forest Management Network, SFM Network Research Note Series No. 57, Edmonton, Alberta.

Luce, C.H., and B.C. Wemple. 2001. Introduction to the special issue on hydrologic and geomorphic effects of forest roads. *Earth Suface Processes and Landforms*. 26:111-113.

Mader, K. 2014. Mitigating impacts of new forest access roads on water levels in forested wetlands: Are cross drains enough? Msc. Thesis Dalhousie University.

Mahaney, W. M., Wardrop, D. H., & Brooks, R. P. (2005). Impacts of sedimentation and nitrogen enrichment on wetland plant community development. *Plant Ecology*, *175*(2), 227-243.

Manitoba Conservation and Water Stewardship. 2012. Forest Practices Guidebook: Forestry Road Management. Government of Manitoba. Pg. 25.

Mallik, A.U. and S. Teichert. 2009. Effects of forest management on water resources in Canada: A research review. National Council for Air and Stream Improvement. p. 80.

McCutchen, N.A. 2007. Factors affecting caribou survival in northern Alberta: the role of wolves, moose, and linear features. Dissertation, University of Alberta, Canada.

McEachern, P. 2016. Forest Watershed and Riparian Disturbance Project (FORWARD). *The Forestry Chronicle*. 92(1): 29-31.

McKenzie, H.W., Merrill, E.H., Spiteri, R.J. and M.A. Lewis. 2012. How linear features alter predator movement and the functional response. *Interface focus.* 2: 205-216.

McKinstry, M.C., and S.H. Anderson. 1994. Evaluation of wetland creation and waterfowl use in conjunction with abandoned mine lands in northeast Wyoming. Wetlands 14(4):284-292.

Mertens, A.J.F. 2018. Spatial variability and controls on surface water chemistry and quality in a heterogeneous landscape: the Western Boreal Forest. MSc. Thesis. University of Alberta. Pg. 136.

Michigan Department of Natural Resources (MDNR) and Michigan Department of Environmental Quality (MDEQ). 2009. Sustainable soil and water quality practices on forest land. MDNR and MDEQ.

Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: wetlands and water Synthesis. World Resources Institute, Washington, DC

Mitsch, W.J. and J.G. Gosselink. 2015. Wetlands. Fifth Edition. John Wiley & Sons, Hoboken, New Jersey.

Murphy, P.N.C., Ogilvie, J., Connor, K., and P.A. Arp. 2007. Mapping wetlands: A comparison of two different approaches for New Brunswick, Canada. *Wetlands.* 27(4): 846-854.

Murphy, P.N.C., Ogilvie, J., Castonguay, M., Zhang, C., Meng, F.R., and P.A. Arp. 2008. Improving forest operations planning through high-resolution flow-channel and wet-areas mapping. *The Forestry Chronicle.* 84(4): 568-574.

Naeth, M.A., Chanasyk, D.S., McGill, W.B., and A.W. Bailey. 1993. Soil temperature regime in mixed prairie rangeland after pipeline construction and operation. *Canadian Agricultural Engineering.* 35(2): 89-95.

National Wetlands Working Group. 1997. The Canadian Wetland Classification System, 2nd Edition. Warner, B.G. and C.D.A. Rubec (eds.), Wetlands Research Centre, University of Waterloo, Waterloo, ON, Canada. 68 p.

Novitzki, R.P., Smith, R.D., and J.D. Fretwell. 1996. Restoration, creation, and recovery of wetlands: Wetland functions, values, and assessment. National Water Summary on Wetland Resources, United States Geological Survey Water Supply Paper 2425.

Nugent, C., Kanali, C., Owende, P.M.O., Nieuwenhuis, M., and S. Ward. 2003. Characteristic site disturbance due to harvesting and extraction machinery traffic on sensitive forest sites with peat soils. 180(1-3): 85-98.

Olson, E.R., and J.M. Doherty. 2012. The legacy of pipeline installation on the soil and vegetation of southeast Wisconsin wetlands. Ecological Engineering. 39: 53-62.

Partington, M., Gillies, C., Gingras, B., Smith, C. and Morissette, J. 2016. Resource roads and wetlands: a guide for planning, construction and maintenance. (Special Publication SP-530E) Pointe-Claire, QC: FPInnovation.. p. 86.

Petrone, R.M., Silins, U. and K.J. Devito. 2006. Dynamics of evapotranspiration from a riparian pond complex in the Western Boreal Forest, Alberta, Canada. *Hydrological Processes*. 21: 1391-1401.

Petrone, R., Devito, K.J., and C. Mendoza. 2016. Utikuma Region Study Area (URSA) – Part 2: Aspen harvest and recovery study. *The Forestry Chronicle.* 92(1): 62-65.

Pilon, J.K. 2015. Characterization of the physical and hydraulic properties of peat impacted by a temporary access road. MSc. Thesis University of Waterloo.

Prepas, E.E., Burke, J.M., Whitson, I.R, Putz, G., and D.W. Smith. 2006. Associations between watershed characteristics, runoff, and stream water quality: hypothesis development for watershed disturbance experiments and modelling in the Forest Watershed and Riparian Disturbance (FORWARD) project. J. Environ. Eng. Sci. 5(Suppl. 1): 27-37.

Pringle, C. 2001. Hydrologic connectivity and the management of biological reserves: A global perspective. *Ecological Applications*. 11(4): 981-998.

Pringle, C. 2003. What is hydrologic connectivity and why is it ecologically important. *Hydrological Processes*. 17: 2685-2689.

Quinton, W.L., Hayashi, M., and A. Pietroniro. 2003. Connectivity and storage functions of channel fens and flat bogs in northern basins. *Hydrological Processes*. 17: 3665-3684.

Ritter, J. 2012. Factsheet: Soil erosion – causes and effects. Ontario Ministry of Agriculture, Food and Rural Affairs. 87-040. Accessed January 19, 2017 < http://www.omafra.gov.on.ca/english/engineer/facts/12-053.pdf >

Robinson, C., Duinker, P.N. and K.F. Beazley. 2010. A conceptual framework for understanding, assessing, and mitigating ecological effects of forest roads. *Environmental Review.* 18: 61-86.

Roulet, N.T. and T.R. Moore. 1995. The effect of forestry drainage practices on the emission of methane from northern peatlands. *Canadian Journal of Forest Research*. 25(3): 491-499.

Rouse, W.R., E.M. Blyth, R.W. Crawford, J.R. Gyakum, J.R. Janowicz, B. Kochtubajda, H.G. Leighton, P. Marsh, L. Martz, A. Pietroniro, H. Ritchie, W.M. Schertzer, E.D. Soulis, R.E. Stewart, G.S. Strong and M.K. Woo. 2003. Energy and water cycles in a high-latitude, north-flowing river system. Summary of results from the Mackenzie GEWEX study – Phase 1. *Bulletin of the American Meteorological Society*. Jan. 2003, 73-87

Roy, V., Ruel, J.-C., and A.P. Plamondon. 2000a. Establishment, growth and survival of natural regeneration after clearcutting and drainage on forested wetlands. *Forest Ecology Management*. 129: 253-267.

Roy, V., Plamondon, A.P., and P.-Y. Bernier. 2000b. Draining forested wetland cutovers to improve seedling root zone conditions. *Scandinavian Journal of Forest Resources.* 15: 58-67.

Rumble, M.A., D.W. Willis, and B.E. Smith. 2004. Wildlife of created palustrine wetlands. Pages 216-239 in M.C. McKinstry, W.A. Hubert, and S.H. Anderson. Wetland and riparian areas of the intermountain west. University of Texas Press, Austin. 319pp.

Ryder et al. 2004. Pipelines and Peat: A review of peat formation, pipeline construction, and reinstatement options. International Conference on Terrain and Geohazard Challenges Facing Onshore Oil and Gas Pipelines. Pp 582-601.

Rydin H., and J.K. Jeglum. 2006. Biology of Peatlands, The. Biology of Habitats Series. Oxford University Press.

Schiks, T.J., Wotton, B.M., Turetsky, M.R., and B.W. Benscoter. 2016. Variation in fuel structure of boreal fens. *Canadian Journal of Forest Research.* 46: 683-695.

Schneider, R.R., Devito, K., Kettridge, N., and E. Bayne. 2016. Moving beyond bioclimatic envelope models: integrating upland forest and peatland processes to predict ecosystem transitions under climate change in the western Canadian boreal plain. *Ecohydrology.* 9: 899-908.

Sheehy, G. for the Wetland Conservation Task Force. 1993. Conserving wetlands in managed forests. Secretariat to the North American Wetlands Conservation Council (Canada). Ottawa, Ontario. p. 36.

Smerdon, B.D., Redding, T.E., and J. Beckers. 2009. An overview of the effects of forest management on groundwater hydrology. *BC Journal of Ecosystems and Management.* 10(1): 22-44.

Smith, K.B., C.E. Smith, S.F. Forest, and A.J. Richard. 2007a. A Field Guide to the Wetlands of the Boreal Plains Ecozone of Canada. Ducks Unlimited Canada, Western Boreal Office: Edmonton, Alberta. 98 pp.

Smith, C., J. Morissette, S. Forest, D. Falk, and E. Butterworth. 2007b. Synthesis of technical information on forest wetlands in Canada. . Technical Bulletin No. 938, National Council for Air and Stream Improvement, Inc., Research Triangle Park, North Carolina.

Soon, Y.L., Arshad, M.A., Rice, W.A., and P. Mills. 2000. Recovery of chemical and physical properties of boreal plain soils impacted by pipeline burial. *Canadian Journal of Soil Science.* 80(3): 489-497.

Strack, M., Softa, D., Bird, M., and B. Xu. 2017. Impact of winter roads on boreal peatland carbon exchange. *Global Change Biology*. Pg. 12.

Sustainable Forestry Initiative (SFI). 2015. SFI 2015-2019 Standards and Rules: Standards, Rules for Label Use, Procedures and Guidance. Washington, DC. http://www.sfiprogram.org/files/pdf/2015-2019-standardsandrules-web-lr-pdf/

Tarnocai, C., Kettles I.M. and Lacelle B. 2002. Peatlands of Canada Database. Geological Survey of Canada, Open File 4002.

Tessmann, S.A. 2004. Management of created palustrine wetlands. Pages 240-276 in M.C. McKinstry, W.A. Hubert, and S.H. Anderson. Wetland and riparian areas of the Intermountain West: ecology and management. University of Texas Press, Austin. 319pp.

Thompson, C., Mendoza, C.A, Devito, K.J., and Petrone, R.M. 2015. Climatic controls on groundwater-surface water interactions within the Boreal Plains of Alberta: Field observations and numerical simulations. *Journal of Hydrology*. 527: 734-746.

Thomson, J. 2016. A peatlands dry out from climate change, wildfire risk increases. CBC News. Accessed January 23, 2017 < http://www.cbc.ca/news/canada/north/drying-peatland-wildfire-risk-1.3655059 >

van der Kamp, G. and P. Marsh. 2013. Threats to Water Availability in Canada. *Chapter 13: Climate Variability and Wetlands*, *from Threats to Water Availiability in Canada*, archived report, <https://www.ec.gc.ca/inre-nwri/default.asp?lang=En&n=0CD66675-1&offset=18&toc=show>. From original report: Environment Canada. 2004. Threats to Water Availability in Canada. National Water Research Institute, Burlington, Ontario. NWRI Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1. 128 p.

Waddington, J.M., Morris, P.J., Kettridge, N., Granath, G., Thompson, D.K., and P.A. Moore. 2015. Hydrological feedbacks in northern peatlands. *Ecohydrology.* 8:113-127.

Warner, B. G. 2004. Geology of Canadian Wetlands. Journal of the Geological Association of Canada 31: 57-68.

Watmough, M.D., and M.J. Schmoll. 2007. Environment Canada's Prairie & Northern Region Habitat Monitoring Program Phase II: Recent habitat trends in the Prairie Habitat Joint Venture. Technical Report Series No. 493. Environment Canada, Canadian Wildlife Service, Edmonton, Alberta.

Wells, J. V., Roberts, D. Lee, P., Cheng, R. and M. Darveau. 2011. A forest of blue: Canada's Boreal Forest, the world's water keeper. Pew Environment Group, Washington.

Wetland Stewardship Partnership. Wetland Ways: Interim Guidelines for Wetland Protection and Conservation in British Columbia. March 2009.

Wetlands Alberta. 2017. Why conserve wetlands? *Wetlands Alberta*. Accessed January 27, 2017 < www.wetlandsalberta.ca/why-conserve-wetlands/ >

Whalley, W.R., Dumitru, E., and A.R. Dexter. 1995. Biological effects of soil compaction. Soil and Tillage Research. 35(1-2): 53-68.

Whiting, D., Card, A., Wilson, C., and J. Reeder. 2014. Soil compaction. Prepared for Colorado State University, Colorado Master Gardener Program. Accessed January 19 2017 < http://www.ext.colostate.edu/mg/gardennotes/215.pdf >

Willier, C. 2017. Changes in peatland plan community composition and stand structure due to road induced flooding and desiccation. Dissertation, University of Alberta.

Yukon Chamber of Mines. 2010. Yukon mineral and coal exploration best management practices and regulatory guide. Yukon Chamber of Mines. Yukon.

Yukon Forest Management Branch. 2011. Forest Resources Regulation: Wetlands Riparian Management Standards and Guidelines. Whitehorse, Yukon.

Appendix One: Wetlands in Forest Management Standards

Cross walk descriptions of how information provided in this document can be used to address some of the requirements of the forest management standards of the three forest certification systems followed in Canada (the Sustainable Forestry Initiative, SFI; the Canadian Standards Association, CSA, and; the Forest Stewardship Council, FSC).

Table A1. Comparison of principles addressed in this document relative to SFI, FSC, and CSA forest management standards.

This Document	SFI 2015 -2019 Forest Management Standard[1]	FSC Canada Standard (Draft 2)[2]	CSA Z809-16 Sustainable Forest Management.[3]
Wetland Stewardship Principles: To conserve wetland resources on the landscape by maintaining wetland quality and quantity as well as other key hydrologic features or processes and regional hydrologic connectivity.	Principle 3. Protection of Water Resources: To protect water bodies and riparian areas, and to conform with forestry best management practices to protect water quality.	The Organization* shall* maintain, conserve* and/or restore* ecosystem services* and environmental values* of the Management Unit*, and shall* avoid, repair or mitigate negative environmental impacts	6.3.3 Criterion 3. Soil and Water. Conserve soil and water resources by maintaining their quantity and quality in forest ecosystems.

Wetland Stewardship Objectives: Approaches to be followed to help deliver on the Wetland Stewardship Principles.	Objective 3. Protection and Maintenance of Water Recourses: To protect the water quality of rivers, streams, lakes, wetlands and other water bodies through meeting or exceeding best management practices	Criterion 6.7. The Organization* shall* protect or restore* natural watercourses, water bodies*, riparian zones* and their connectivity*. The Organization* shall* avoid negative impacts on water quality and quantity and mitigate and remedy those that occur.	6.3.3.4 Element 3.2 – Water Quality and Quantity. Conserve water resources by maintaining water quality and quantity.
Planning Considerations. Practices to consider to help achieve Wetland Stewardship Objectives.	Performance Measure 3.2. Program Participants shall implement water, wetland and riparian protection measures based on soil type, terrain, vegetation, ecological function, harvesting system, state best management practices (BMPs), provincial guidelines and other applicable factors.	Indicator 6.7.1. Best management practices* are in place and being effectively implemented to protect water bodies*, riparian zones*, and water quality.	Core indicators 3.2.1 — Proportion of watershed or water management areas with recent stand-replacing disturbance. 3.2.2 — Proportion of forest management activities, consistent with prescriptions to protect identified water features.

[1]SFI 2015

[2]FSC 2016

[3]CSA 2016

*refers to definitions within the standard

Appendix Two: Wetland Classification Systems

Wetland Definition

A variety of wetland definitions exist within Canada. In this report we use the definition developed by the National Wetlands Working Group; however, it is important to recognize that other definitions exist and that these definitions may be more applicable depending on the jurisdiction and the application.

Government of Alberta, Alberta Wetland Policy (Alberta Environment and Sustainable Resource Development, AESRD 2015):

"Land saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydro-phytic (water loving) vegetation, and various kinds of biological activity that are adapted to a wet environment."

Sustainable Forestry Initiative, SFI 2015 – 2019 Standards and Rules (SFI 2015):

"(1) seasonally or permanently water-logged areas characterized by vegetation adapted for life in saturated /flooded conditions; (2) wetlands can be forested, shrubby or open and include bogs, fens, swamps, marshes and shallow open water areas; (3) wetlands may be stagnant systems (e.g., bogs), slow flowing (e.g., fens, swamps) or have fluctuating water levels (e.g., marshes, shallow open water)."

Canadian Standards Association, CSA Z809- 16 Forest Management Standard (CSA 2016):

"areas that are seasonally or permanently waterlogged and characterized by vegetation adapted for life in saturated/flooded conditions. Wetlands can be treed, shrubby or open and include bogs, fens, swamps, marshes and shallow open water areas. Some wetlands are stagnant systems (e.g., bogs), slow flowing (e.g., fens, swamps), or have fluctuating water levels (e.g., marshes, shallow open water)."

Forest Stewardship Council, FSC Canada National Forest Management Standard (Draft 2; FSC 2016):

"Transitional areas between terrestrial and aquatic systems in which the water table is usually at or near the surface or the land is covered by shallow water. Under the Ramsar Convention, wetlands can include tidal mudflats, natural ponds, marshes, potholes, wet meadows, bogs, peatlands, freshwater swamps, mangroves, lakes, rivers and even some coral reefs."

Wetland Classification

As discussed in Chapter Two, there is no single classification system that is used consistently across the country. Below are more detailed information on the five major wetland classes summarized in Chapter Three and information on other classification systems.

Five Major Wetland Classes

Bogs: are peatlands that receive water only through precipitation, are nutrient poor and are usually isolated from groundwater and surface run-off. Under average climatic conditions, bogs are often characterized as being stagnant, no or low flowing systems with low plant diversity due to low nutrient availability. However under sustained above average precipitation, some bogs can essentially flood becoming water source areas. The surface of a bog is typically dry, but the thick peat below is saturated with water like a wet sponge. All bogs have a thick ground cover of *Sphagnum* mosses. Most bogs contain varying densities of stunted black spruce and low-lying ericaceous shrubs.

Fens: are peatlands that receive water through a combination of precipitation, surface runoff and groundwater sources. They are more nutrient rich than bogs because of surface and groundwater inputs resulting in greater plant species diversity than bogs. Fens can be nutrient rich or nutrient poor depending on water sources and nutrient availability/input. Nutrient-poor fens more closely resemble bogs, while nutrient-rich fens have more diverse and robust vegetation communities. Fens are hydrologically complex with high water tables, and can transport large volumes of water and nutrients across the landscape often connecting wetland systems over large distances.

Swamps: are mineral based wetlands that may have deeper (e.g., greater than 40cm) peat soils. These wetlands are diverse and are sometimes referred to as lowland forests, forested wetlands, treed swamp forests, wooded swamps, or shrub swamps. They are commonly recognized as shoreline areas of streams, lakes and floodplains. Swamps receive water from run-off, precipitation and groundwater sources. Water movement ranges from stagnant to dynamic. In these dynamic systems, the water table fluctuates and seasonal flooding may occur. The periodic drying out and oxygenation of swamp soils helps develop fertile soils that are capable of supporting a diversity of robust trees, shrubs and other plants. Swamps are distinguished from other wetlands and from upland forests by the combination of hummocky ground that may contain pools of water and by a tall dense canopy of water tolerant shrubs and/ or trees.

Marsh:

Shallow Open Water:

These five major types of wetlands can be further classified in a number of different ways and there is no single classification system that is used consistently across the country. For example, the CWCS also divides wetlands by form according to wetland morphology (e.g., surface form and pattern) water characteristics (e.g., source and type), and geological characteristics (e.g., basin depth and shape, soil properties) and then by type according to vegetation community. The Alberta Wetland Classification System (AWCS; AERSD 2015) breaks the 5 major classes into 13 forms which are subdivided into types based on biological, hydrological or chemical attributes. Ducks Unlimited Canada has developed an ecologically - based Enhanced Wetland Classification (EWC) system for the Boreal Plains ecozone that categorizes the 5 major classes of wetlands into 19 minor classes based on soil, vegetation, and hydrology (Smith et al. 2007a) . The EWC minor classes differentiate bog and fens into nutrient rich and nutrient poor minor wetland classes, while the forms of the AWCS make no such differentiation. The following table cross-references similar wetland types found in the CWCS, EWC, and AWCS (DUC unpublished reference chart 2016).

Table A2. Comparison of minor classes of the EWC and form of AWCS

EWC/CWCS/AWCS Major Class	AWCS Form (analogous to EWC minor class)	EWC Minor Class
Shallow Open Water	Submersed and/or Floating Aquatic Vegetation	Aquatic Bed
	Bare Shallow Open Water	Open Water
		Mudflats
Marsh	Graminoid Marsh	Emergent Marsh
		Meadow Marsh
Swamp	Coniferous Wooded Swamp	Tamarack Swamp
		Conifer Swamp
	Wooded, Deciduous Swamp	Hardwood Swamp
	Wooded, Mixedwood Swamp	Mixedwood Swamp
	Shrubby Swamp	Shrub Swamp
Fen	Wooded, Coniferous Fen	Treed Rich Fen
		Treed Poor Fen
	Shrubby Fen	Shrubby Rich Fen
		Shrubby Poor Fen
	Graminoid Fen	Graminoid Rich Fen
		Graminoid Poor Fen
Bog	Wooded, Coniferous Bog	Treed Bog
	Shrubby Bog	Shrubby Bog
	Graminoid Bog	Open Bog

Geographic variations

Peatlands (bogs and fens) are the most abundant wetlands in Canadian forests (approximately 86% of all wetlands in Canada, Tarnocai et al. 2002). In fact, peatlands comprise more than 30% of Ontario and Manitoba’s land mass and over 20% in Alberta. Peatlands are more common in cool and relatively flat northern forests of Alberta, Saskatchewan, Manitoba, Ontario and Quebec, and are less common in mountainous areas of British Columbia and Yukon, where surface water moves quickly.

Peatlands are also common throughout most of Newfoundland and Labrador, in eastern and southern New Brunswick, and in southwestern Nova Scotia (primarily bogs occur New Brunswick and Nova Scotia, since the climate is cool and the land is generally flat and has poor drainage).

Swamps in northern forests commonly border streams or flowing water systems, but can also be more extensive in some locations. In middle-latitude forests, coniferous swamps may be locally common on gently sloping areas covered by shallow peat. In the more southern forests of Quebec and Ontario, coniferous and hardwood swamps commonly occur on the floodplains of lakes, rivers, and streams. In the eastern provinces, swamps are common near streams and shores, occurring primarily as conifer swamps or shrub swamps.

Compared to other wetland types, marshes are less abundant in forested regions, occurring mainly within inland deltas or along the shores of lakes and larger stream systems and sometimes as isolated marsh wetlands.

The local and regional distribution and diversity of wetlands in Canadian forests is a function of bedrock and surficial geology, topography and climate. For example:

- Hudson Plains ecozone: The flat terrain, impervious soil, poor drainage and cool, moist climate promote the development of wetlands throughout much of this ecozone, resulting in the highest densities of wetlands and the largest wetland complexes in the world.
- Boreal Plains ecozone: The relatively dry climate, flat to gently rolling terrain and varying amounts of surficial geology allow for a landscape rich with various wetland types that are often highly connected.
- Boreal Shield ecozone: The humid climate, shallow soils and millions of depressions among impermeable bedrock have resulted in the highest number of wetland hectares in Canada.
- Atlantic Maritime ecozone: This is one of the most diverse areas in Canada in terms of climate, topography, and ecology, resulting in the formation of various types of wetlands, from freshwater wetlands in undulating lowlands to peatlands in poorly drained areas. Wetlands are a major component of the Maritime landscape, but they are relatively less abundant here than in other areas of Canada.
- Cordillera ecozones: Wetlands here are found in the flat, poorly drained areas of the plateaus and valleys of the mountainous sedimentary bedrock terrain. Although there are areas with extensive wetland complexes, fewer wetlands occur in these ecozones than in other areas of Canada.

Appendix Three: Wetland Flow Characteristics

Table A3.1. The primary factors that influence water flow in forested environments

RANGE TO CONSIDER

ORDER OF IMPORTANCE IN MAKING PREDICTIONS OF HYDROLOGY

CLIMATE	**Dry, arid to sub humid** • Greater water storage potential • Vertical flow dominates • Runoff poorly coordinated with precipitation	**Wet, humid** • Less water storage potential • Lateral flow dominates • Runoff closely correlated with precipitation
BEDROCK GEOLOGY	**Permeable** • Vertical subsurface flow dominates **Bedrock slope perpendicular to surface** • Complex watershed boundaries	**Impermeable** • Lateral surface flow dominates **Bedrock slope parallel to surface** • Simple watershed boundaries
SURFICIAL GEOLOGY	**Deep substrate** • Intermediate to regional flows **Coarse grained** • Groundwater and subsurface flow **Spatially varied deposits** • Complex groundwater flow	**Shallow substrate** • Local flows most probably **Fine grained** • Surface/shallow subsurface flow and depression storage **Spatially uniform deposits** • Simple groundwater flow
SOIL TYPE AND DEPTH	**Upland mineral soils** • Subsurface flow dominates • Deeper soils • Large water storage potential • Little runoff generation	**Lowland organic soils** • Surface flow dominates • Shallower soils • Small water storage potential

	• Deep rooted vegetation with access to stored water	• Greater runoff generation • Shallow rooted vegetation with limited access to stored water
TOPOGRAPHY AND DRAINAGE NETWORK	**Gentle slopes** • Disorganized drainage network • Small, variable runoff • Large groundwater recharge	**Steep slopes** • Organized drainage network • Large, uniform runoff • Less groundwater recharge

**Adapted from Devito et al. (2005)*

Wetland flow characteristics

Consider the wetland type when choosing the wetland crossing type and design

When crossing ***Stagnant*** wetlands consider that they:

- receive water from rain or snow usually resulting in minor water level seasonal fluctuations
- under average climatic conditions, are usually isolated from other wetland systems and from mineral ground water but can become saturated and produce run off during periods of above average precipitation
- stagnant wetlands are not without flow, they may have no to gradual flow
- are unlikely to have a defined stream channel and that water is often present at or below the surface
- may have a very deep organic layer with a minimum depth of organic material >40cm

When crossing ***Moving – Slow Lateral Flow*** wetlands consider that they:

- receive water from precipitation, runoff and groundwater
- are typically connected to adjacent wetlands and may demonstrate small flow “channels”
- usually have slow moving flows at and below the surface, including continuous seepage
- may experience an increase in volume and velocity of flow during peak rainfall or snow melt events
- are less susceptible to freezing due to year-round surface and subsurface water movement
- may have a very deep organic layer with a minimum depth of organic material >40cm

When crossing ***Moving – Seasonally Fluctuating*** wetlands consider that they:

- receive water from precipitation, runoff and groundwater
- are often part of a flowing water system

- usually have slow moving flows at and below the surface may flood above the root mat in spring and after heavy rain when significant water flow can be expected, but can be dry in the middle of the summer
- often have small defined channels of concentrated ephemeral surface flow or shallow subsurface flow (e.g., shrub swamps)
- typically have shallow organic soils (<40cm), although conifer swamps may have organic depths >40 cm in some locations

When crossing ***Inundated/Flooded*** wetlands consider that they:

- receive water from precipitation, runoff and groundwater
- water levels may fluctuate seasonally and/or annually and may not go above surface level (appear dry)
- can sometimes be connected to flowing (e.g., streams and/or creek) systems
- may be considered or contain fish habitat
- should only be considered for crossing in the winter season

When crossing a ***Wetland Complex*** (several wetlands connected together) consider:

- designing the crossing to accommodate the most dynamic water flow conditions.

Table A3.2. Summary of water source, hydrologic connections, and soils by hydrologic grouping.

Hydrologic grouping	Water source			Hydrologic connections			Soils	
	Precipitation	Runoff	Ground water	Isolated	Connected	Annual or seasonal fluctuations	Organic	Mineral
Stagnant	X			X	X		X	
Slow lateral flow	X	X	X		X		X	
Seasonally fluctuating	X	X	X		X	X	X	X
Inundated / flooded	X	X	X	X	X	X		X

Appendix Four: Wetland Stewardship Principles

These principles are important components of Canada's forest certification standards:

- SFI 2015-2019 Forest Management Standard: Objective 3. Protection and maintenance of water resources: To protect the water quality of rivers, streams, lakes, wetlands and other water bodies through meeting or exceeding best management practices.
- FSC Canada Standard (Draft 2): Principle 6. Principle Environmental impact: Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest.
- CSA Z809-16 Sustainable Forest Management: 6.3.3 Criterion 3. Soil and Water. Conserve soil and water resources by maintaining their quantity and quality in forest ecosystems.

Appendix Five: Regulatory and Voluntary Forest Management Requirements for Each Wetland Stewardship Objective

Chapter Five outlined seven wetland stewardship objectives as approaches to conserve wetland resources and are aligned with many current mandatory (i.e. regulatory) or voluntary forest management requirements in Canada. Below are some of the legal or certification requirements that relate to each wetland stewardship objective found in Chapter Five.

Objective 1: Avoid or minimize blockage or disruption of wetland surface and subsurface water flow

Similar or matching legal or certification requirements relating to water flow include:

- SFI 2015-2019 Forest Management Standard: Performance Measure 3.2. Indicator 1. Program addressing management and protection of rivers, streams, lakes, **wetlands**, other water bodies and riparian areas during all phases of management, including the layout and construction of roads and skid trails to maintain water reach, **flow** and quality.
- SFI 2015-2019 Forest Management Standard: Performance Measure 3.2. Indicator 3. Documentation and implementation of **plans to manage and protect** rivers, streams, lakes, **wetlands,** other water bodies and riparian areas.
- FSC Canada Standard (Draft 2): Criterion 6.7.1. Best management practices* are in place and being effectively implemented to protect water bodies*, riparian zones*, and water quality.
- FSC Canada Standard (Draft 2): Criterion 6.7.3 Appropriate to the Scale Intensity and Risk* of operations, Best Management Practices* are in place and are being effectively implemented to control changes in flow in watersheds with significant downstream values resulting from management activities*.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 11.4 Watercourse Crossings.
- Manitoba stream crossing guidelines for the protection of fish and fish habitat (XXX1996): Route planning. Includes recommendations to:
    - Design routes that are consistent with topography.
    - Avoid wetlands and marshes, steep slopes and unstable or erodible soils.

- Forestry Road Management (Manitoba Conservation and Water Stewardship, 2012): Water crossings
    - "Wetland crossings should maintain natural drainage"
- British Columbia Standards and best Practices for Instream Works (WLAP, 2004): 7.1.3 Standards for stream crossings. Wetlands are included in the definition of 'stream' and covered by this guide.

Objective 2: Avoid or minimize soil compaction

Similar or matching legal or certification requirements relating to soil compaction include:

- SFI 2015-2019 Forest Management Standard: Performance Measure 3.2. Indicator 3. Documentation and implementation of **plans to manage and protect** rivers, streams, lakes, **wetlands,** other water bodies and riparian areas.
- SFI 2015-2019 Forest Management Standard: Performance Measure 2.3 Indicator 1. Process to identify soils vulnerable to **compaction**, and use of appropriate methods, including the use of soil maps where available, to avoid excessive soil disturbance.
- FSC Canada Standard (Draft 2): Criterion 6.7.1. Best management practices* are in place and being effectively implemented to protect water bodies*, riparian zones*, and water quality.
- FSC Canada Standard (Draft 2): Criterion 6.3.1. Appropriate to the scale, intensity and risk* of the forest management activities*, Management Plans* or associated documents (for example Ground Rules, Standard Operating Procedures, etc.) based on best management practices* identify means to protect **soils** from physical damage.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 9.0 Soils.

Objective 3: Avoid or minimize soil layer disturbance

Similar or matching legal or certification requirements relating to soil layer disturbance include:

- SFI 2015-2019 Forest Management Standard: Performance Measure 3.2. Indicator 3. Documentation and implementation of **plans to manage and protect** rivers, streams, lakes, **wetlands,** other water bodies and riparian areas.
- SFI 2015-2019 Forest Management Standard: Performance Measure 2.3 Indicator 1. Process to identify soils vulnerable to compaction, and use of appropriate methods, including the use of soil maps where available, to **avoid excessive soil disturbance.**
- FSC Canada Standard (Draft 2): Criterion 6.7.1. Best management practices* are in place and being effectively implemented to protect water bodies*, riparian zones*, and water quality.
- FSC Canada Standard (Draft 2): Criterion 6.3.1. Appropriate to the scale, intensity and risk* of the forest management activities*, Management Plans* or associated documents (for example Ground Rules, Standard Operating Procedures, etc.) based on best management practices* identify means to protect **soils** from physical damage.
- Albert Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 9.0 Soils.
- Manitoba Forest Management Guidelines for Riparian Management Areas (Manitoba Conservation and Water Stewardship, 2008): Objective protect water quality

Objective 4: Maintain structure and function of riparian and wetland vegetation

Similar or matching legal or certification requirements relating to riparian and aquatic vegetation include:

- SFI 2015-2019 Forest Management Standard: Performance Measure 3.2. Indicator 3. Documentation and implementation of **plans to manage and protect** rivers, streams, lakes, **wetlands,** other water bodies and riparian areas.
- FSC Canada Standard (Draft 2): Criterion 6.7.1. Best management practices* are in place and being effectively implemented to protect water bodies*, riparian zones*, and water quality.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 6.0 Watershed Protection.

Objective 5: Avoid or minimize increased site level run-off and erosion

- SFI 2015-2019 Forest Management Standard Performance Measure 3.2. Indicator 1. Program addressing management and protection of rivers, streams, lakes, **wetlands**, other water bodies and riparian areas during all phases of management, including the layout and construction of roads and skid trails to maintain water reach, flow and **quality.**
- SFI 2015-2019 Forest Management Standard Performance Measure 3.2. Indicator 4. Plans that address wet-weather events in order to maintain water quality (e.g., forest inventory systems, wet-weather tracts, definitions of acceptable operating conditions).
- SFI 2015-2019 Forest Management Standard: Performance Measure 2.3 Indicator 2. Use of **erosion** control measures to minimize the loss of soil and site productivity.
- FSC Canada Standard (Draft 2): Criterion 6.3.1. Appropriate to the scale, intensity and risk* of the forest management activities*, Management Plans* or associated documents (for example Ground Rules, Standard Operating Procedures, etc.) based on best management practices* identify means to protect **soils** from physical damage.
- FSC Canada Standard (Draft 2): Criterion 6.7.1. Best management practices* are in place and being effectively implemented to protect water bodies*, riparian zones*, and water quality.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 6.0 Watershed Protection.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 9.0 Soils.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 11.3 Road Construction, Maintenance and Reclamation.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 11.4 Watercourse Crossings.
- BC Forest Planning and Practices Regulation (B.C. Government, 2016): Part 4 – Practice Requirements, Division 1 – Soils 40 (b) Revegetation
    - "person who constructs or deactivates a road must ensure that soil exposed by construction is revegetated […] the revegetation would materially reduce the likelihood of erosion."
- Manitoba Forest Management Guidelines for Riparian Management Areas (Manitoba Conservation and Water Stewardship, 2008): Objective to prevent erosion and maintain water quality.

Objective 6: Prevent sediment and pollutants from entering the wetland

Similar or matching legal or certification requirements relating to sediment and other pollutants include:

- SFI 2015-2019 Forest Management Standard: Performance Measure 3.2. Indicator 3. Documentation and implementation of **plans to manage and protect** rivers, streams, lakes, **wetlands,** other water bodies and riparian areas.
- SFI 2015-2019 Forest Management Standard: Performance Measure 2.2. Indicator 8g. Use of management practice appropriate for the situation, for example, monitoring of water quality or safeguards to ensure proper equipment use and protection of streams, lakes and other waterbodies.
- FSC Canada Standard (Draft 2): Criterion 6.7.1. Best management practices* are in place and being effectively implemented to protect water bodies*, riparian zones*, and water quality.
- FSC Canada Standard (Draft 2): Criterion 10.12.1. Ground rules or operational procedures related to handling of chemicals, liquid and solid non-organic wastes, including fuel, oil, batteries and containers are in place and are implemented. The management standards identified in procedures are consistent with high levels of performance and best management practices*.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 6.0 Watershed Protection.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 11.3 Road Construction, Maintenance and Reclamation.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 11.4 Watercourse Crossings.
- BC Timber Harvesting and Silviculture Practices Regulation (Forest Practices Code of BC Act, 2002): Section 11(3) Restricted operation of machinery
    - ” A holder of an agreement under the Forest Act who carries out harvesting or silviculture treatment must not fuel or service machinery in a riparian management area of a stream or wetland or within 30m of a lakeshore.”
- BC Timber Harvesting and Silviculture Practices Regulation (Forest Practices Code of BC Act, 2002): Section 27(a) Requirements when constructing excavated or bladed trails
    - “A holder of an agreement under the Forest Act who is constructing excavated or bladed trail must comply with the following: (a) must not deposit soil material that has been excavated to construct the trail or slash in a stream, wetland or…”
- BC Forest Planning and Practices Regulation (B.C. Government, 2016): Part 4 – Practice Requirements, Division 1 – Soils 40 (a) Revegetation
    - “person who constructs or deactivates a road must ensure that soil exposed by construction is revegetated […] the erosion of the soil would cause sediment to enter a stream wetland or alke…”

Objective 7: Avoid or minimize invasive species introduction and/or spread

Similar or matching legal or certification requirements relating to invasive species include:

- SFI 2015-2019 Forest Management Standard: Performance Measure 3.2. Indicator 3. Documentation and implementation of **plans to manage and protect** rivers, streams, lakes, **wetlands,** other water bodies and riparian areas.

- SFI 2015-2019 Forest Management Standard: Performance Measure 4.1. Indicator 7. Participation in programs and demonstration of activities as appropriate to **limit the introduction, spread and impact of invasive** exotic plants and animals that directly threaten or are likely to threaten native plant and animal communities.
- FSC Canada Standard (Draft 2): Criterion 10.3.2. A plan to **prevent the spread of invasive** species introduced by The Organization* is developed and implemented in a timely manner* and/or within The Organization's* sphere of influence*. (Adapt - was IGI 10.3.3)

Appendix Six: Planning Considerations Supporting Information

Map the distribution of wetlands on the landscape by type

Using several sources of information to help identify, map and classify wetlands is identified as an important practice in a number of government, certification, public and joint documentation:

Government

- Alberta Wetland Policy Implementation (Government of Alberta 2016) "The first step is landscape-level scoping using new and existing tools to do a preliminary desktop review of ownership, identify and delineate wetlands, and estimate the relative value of the wetlands"
- BC Gov Biogeoclimatic Ecosystem Classification Program (Government of British Columbia 2017) "However, this type of classification system [simple, based primarily on wetland size], while administratively easy to apply, does not reflect natural variation in the sensitivity or ecological function of different wetland types that occur in British Columbia." "A system that more explicitly addresses this variability would enable the development of more site specific best management practices as well as interpretations for landscape planning, risk ranking, and wildlife habitat evaluation."
- Yukon Forest Management Branch (2011) "when developing forest plans, wetlands will be identified according to one of five wetland classes – bog, fen, swamp, marsh, and shallow water – in accordance with the Canadian Wetland Classification System (CWCS)."
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 3.4. Forest Harvest Plan
    - Section 3.4.5 Maps shall accurately show the following information:
        - Digital files for all laid out for harvest area boundaries, interblock roads, and watercourse crossing location.
        - Identified watercourses, springs, water source and seepage areas

Certification

- FSC – Principle 6, 6.1, 6.1.1 "Best available information* is used to identify and define the state and condition of regional- and landscape*-scale* environmental values* within, and where potentially affected by management activities*, outside of the Management Unit*"; 6/4. "Hydrologic features* (maps); 6.5. "Lake, stream and wetland* classifications including identification of fish-bearing water bodies (maps and quantitative summaries).
- SFI – Performance Measure 3.2, Indicator 1: "Mapping of rivers, streams, lakes, wetlands and other water bodies as specified in state or provincial best management practices and, where appropriate, identification on the ground".

- SFI – Performance Measure 4.1, Indicator 6: "Identification and protection of non-forested wetlands, including bogs, fens and marshes, vernal pools of ecological significance".
- CSA – A.6.3.3.4 Element 3.2. "Having detailed maps of surface water and wetland systems can help identify areas within a management area where certain planning, avoidance and mitigation strategies might be required".

Public

- Murphy, et al. (2007) "a basic need for setting clear policy objectives and effective management with regard to wetlands is the development of knowledge inventories concerning the location, size, and type of wetlands."

Joint

- Wetland Ways Interim Guidelines for Wetland Protection and Conservation in British Columbia (Wetland Stewardship Partnership 2009) 'Section 2.3 (Objectives): "…three primary objectives for protection and management of wetlands: 1) protect and maintain habitats and species, 2) protect and maintain water quantity, 3) protect and maintain water quality. This can be achieved by: knowing what you have (inventory and mapping)…" Section 2.4 (Guidelines): "identify the 'type' or 'class' of wetland you are managing […] determine the features and functions that the wetland currently provides or could provide with appropriate buffers.."..."

Avoid new disturbances to wetlands by participating in integrated land management planning

Participating in integrated land management planning is identified as an important practice in a number of government, industry and certification documentation:

Government

- Joint planning among forest companies to reduce disturbance is included in the current Alberta Timber Harvest Planning and Operating Ground Rules (section 5.1; AESRD 2012) however, there is no mechanism in place to require joint planning with other industrial stakeholders (e.g., oil and gas industry) working on the landscape.
- Integrated Land Management (Government of Alberta 2010)
- Best management practices related to land management (Government of Alberta 2013b)

Industry

- Evolving Approaches to Minimize the Footprint of the Canadian Oil and Natural Gas Industry (Canadian Association of Petroleum Producers 2004)
- Alberta Pacific Forest Industries Inc. Integrated Landscape Services (2017)

Certification

- CSA – 6.3.1. Criterion 1 – Biological Diversity; 6.3.1.2 Discussion Items for Criterion 1. "local and regional protected areas and integrated landscape management".

- FSC – 6.8.5 The Organization* works within its sphere of influence* with managers, agencies and Indigenous Peoples* responsible for managing lands adjoining the forest* to coordinate approaches to landscape*-level management, including:
    1. Management to facilitate landscape*-scale* connectivity*;
    2. Management of access so as to minimize cumulative disturbances; and
    3. Maintenance and/or restoration of large contiguous areas.

Avoid new disturbances to wetlands by locating new infrastructure projects near or on existing disturbances and plan access routing to accommodate future development needs

Using existing infrastructure and/ or re-using disturbed or recently disturbed sites are identified as an important practices in a number of government documents:

Government

- Integrated Land Management Tools Compendium (Government of Alberta 2012)
- Integrated Land Management (Government of Alberta 2010)
- Best management practices related to land management (Government of Alberta 2013b)
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 11.3 Road Construction, Maintenance and Reclamation "Existing access (e.g., seismic lines, trails, and existing roads) shall be used as a priority wherever practical and feasible.

Prioritize wetlands for avoidance based on ecological, social, and economic factors

- "Not all wetlands are of equal value. Alberta's wetlands are highly diverse in form, function, use, and distribution across the province. Under the Alberta Wetland Policy, wetland value will be assessed based on relative abundance on the landscape, supported biodiversity, ability to improve water quality, importance to flood reduction, and human uses. Individual wetlands will be assessed against these key criteria and assigned an overall wetland value. Relative wetland value will be used to inform wetland management" (Government of Alberta 2013a)
- "Not all wetlands perform all functions nor do they perform all functions equally well" (Novitzki et al. 1996).
- Gustavson, K., and E. Kennedy. 2010. Approaching wetland valuation in Canada. *Wetlands*, *30* (6), 1065-1076.

Certification

- SFI – Performance Measure 4.1, Indicator 6: "Identification and protection of non-forested wetlands, including bogs, fens and marshes, vernal pools of ecological significance".

Consider timing, location and equipment when working in or near wetlands in relation to climate, bedrock and surficial geology, soils, and topography and drainage network

- Devito, K., Creed, I., Gran, T., Mendoza, C., Petrone, R., Silins, U. and B. Smerdon. 2005. A framework for broad-scale classification of hydrologic response units on the Boreal Plain: is topography the last thing to consider. *Hydrological Processes.* 19: 1705-1714.

- Smerdon, B.D, and C.A. Mendoza. 2010. Hysteretic freezing characteristics of riparian peatlands in the western boreal forest of Canada. *Hydrological Processes*. 24: 1027-1038.
- Devito, K., Mendoza, C. and C. Qualizza. 2012. Conceptualizing water movement in the Boreal Plains: Implications for watershed reconstruction. Synthesis report prepared for the Canadian Oil Sands Network for Research and Development, Environmental and Reclamation Research Group. 164pp.
- Donnelly, M., Devito, K., Mendoza, C., Petrone, R., and M. Spafford. 2016. AlPac Catchment Experiment (ACE). *The Forestry Chronicle.* 92(1): 23-26.

Consider the location of planned access, harvest, and renewal activities in relation to wetlands, including: key attributes and function of different wetland types, position of wetland in the watershed, wetland connectivity

Government

- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 3.4. Forest Harvest Plan
  - Section 3.4.5 Maps shall accurately show the following information:
    - Digital files for all laid out for harvest area boundaries, interblock roads, and watercourse crossing location.
    - Identified watercourses, springs, water source and seepage areas
  - Section 3.4.8 Where applicable the following comments shall be mapped and/or described for each harvest area
  - Section 3.4.9 Detailed harvest plans (DHAP) are required when there is higher than average potential for environmental damage. Circumstances that merit DHAPs are:
    - Harvest areas with numerous water source areas, seepages, intermittent or ephemeral watercourses.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 9.0 Soils
  - Section 9.1 Areas susceptible to rutting, puddling, or compaction should be avoided when planning temporary roads, decks, landings and skidding patterns
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 11.3 Road Construction, Maintenance and Reclamation
  - Section 11.3.1.2 Roads and landings shall be constructed to avoid:
    - Unstable soils, water source areas, springs and seepage areas
    - Creating disturbed, compacted or bare soils that exceed the amount specified in section 9.3 - soils
  - Section 11.3.2.1 Roads, skid trails and landings shall be placed in locations and constructed so that soil erosion, damage to streambeds and sedimentation of watercourses are minimized.

Literature

- Partington et al. 2016.

Certification

- SFI – Performance Measure 2.3, Indicator 1: "Process to identify soils vulnerable to compaction, and use of appropriate methods, include the use of soil maps where available, to avoid soil disturbance".
- SFI – Performance Measure 2.3, Indicator 6: "Road construction and skidding layout to minimize impacts to soil productivity".
- FCS Draft – Criterion 6.1.2 Best Available Information is used to identity and define the state and condition of stand and site-scale environmental values within the Management Unit. Consistent with the scale, intensity and risk of the operation, Best Available Information includes:
    - 3. Sensitive sites, including steep slopes, wetlands and soils subject to compaction (for example, structured clay) (mapped information)
- FCS Draft – Criterion 6.3.1. Appropriate to the scale, intensity and risk of the forest management activities, Management Plans or associated documents (for example Ground Rules, Standard Operating Procedures, etc.) based on best management practices identifying means to protect soils from physical damage. The best management practices related to the protection of soils from physical damage address the following.
    - 1. Prior identification of unstable soils and ground surfaces, and sites sensitive to compaction, rutting, and erosion (for example, wetlands)
- FSC Criterion 6.7.1 Best management practices are in place and being effectively implemented to protect water bodies, riparian zones, and water quality. At a minimum, measures address the following:
    - Minimizing disruption of natural drainage patterns, including when locating and constructing roads, landings and skidways
- CSA – A.6.3.3.4 Element 3.2. "Having detailed maps of surface water and wetland systems can help identify areas within a management area where certain planning, avoidance and mitigation strategies might be required".
- Wetland Ways Interim Guidelines for Wetland Protection and Conservation in British Columbia,

Located wetland crossings to create the least amount of disturbance

- Willier C. 2017. Changes in peatland plant community composition and stand structure due to road induced flooding and desiccation. Master's Thesis. Accessed October 15th 2017 from https://era.library.ualberta.ca/files/ccz30pt16h/Willier_Caitlin_N_201706_MSc.pdf

Consider the wetland type when choosing the wetland crossing type and design

Certification

- SFI – Performance Measure 3.2, Indicator 1: Program addressing management and protection of rivers, streams, lakes, wetlands, other water bodies and riparian areas during all phases of management, including the layout and construction of roads and skid trails to maintain water reach, flow and quality.
- FCS – Criterion 6.7.3 Appropriate to the Scale Intensity and Risk* of operations, Best Management Practices* are in place and are being effectively implemented to control changes in flow in watersheds with significant downstream values resulting from management activities*. The measures include:

- Avoiding subsurface and surface drainage interception and/or diversion by roads and trails;

Plan to schedule activities to occur during favourable weather conditions

Government

- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Table 2. Standards and Guidelines for Operating Besides Watercourses.
  - Water source areas and areas subjected to normal seasonal flooding
    - Heavy equipment is not permitted during moist or wet soil conditions, but may be operated during frozen ground
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 9.0 Soils
  - Section 9.2 Areas susceptible to rutting, puddling, or compaction shall be harvested during dry or frozen conditions (e.g. harvest areas with predominately imperfectly-poorly drained soils).
  - Section 9.4 Operations shall not occur during heavy rainfall or when soil conditions are above field capacity (saturated)

Certification

- SFI – Performance Measure 3.2, Indicator 4: "Plans that address wet-weather events in order to maintain water quality (e.g. forest inventory systems, wet-weather tracts, definition of acceptable operating conditions)"
- FCS Draft –Criterion 6.3.1. Appropriate to the scale, intensity and risk of the forest management activities, Management Plans or associated documents (for example Ground Rules, Standard Operating Procedures, etc.) based on best management practices identifying means to protect soils from physical damage. The best management practices related to the protection of soils from physical damage address the following.
  - 4. Use of alternative harvesting and site preparation equipment (for example low ground pressure equipment) and other mitigation measures, such as seasonal timing, and temporary suspension of activities during unfavourable weather to minimize soil rutting and compaction; and

Plan to reduce soil compaction, soil disturbance, erosion and sedimentation

Government

- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 3.4. Forest Harvest Plan
  - Section 3.4.8 Where applicable the following comments shall be mapped and/or described for each harvest area:
    - Soil protection measures when any of the following are present:
      - Identified areas, water-source areas, springs, or seepages
      - Steep or sustained slopes or grates (>30%)
      - Unfrozen operating conditions

- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 6. Watershed Protection
    - Section 6.0.3. Measures must be implemented, including temporary and permanent erosion control measures to minimize erosion and sedimentation into the watercourse or waterbody
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 9.0 Soils
    - Section 9.1 Areas susceptible to rutting, puddling, or compaction should be avoided when planning temporary roads, decks, landings and skidding patterns
    - Section 9.5 minimize the machine traffic on sensitive areas, depending on soil susceptibility to disturbance according to the results of the hand test
    - Section 9.6 Operations shall cease when instanced of multiple ruts in a limited area are created that are clearly related to operations during unfavorable ground conditions.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 11.3 Road Construction, Maintenance and Reclamation
    - Section 11.3.1.2 Roads and landings shall be constructed to avoid.
        - Unstable soils, water source areas, springs and seepage areas
        - Creating disturbed, compacted or bare soils that exceed the about specified in section 9.3 - soils
    - Section 11.3.2.1 Roads, skid trails, and landings shall be placed in locations and constructed so that soil erosion, damage to streambeds and sedimentation of watercourses are minimized.
    - Section 11.2.2.2 Constructed roads require erosion control and stabilization of disturbed soils.

Certification

- SFI – Performance Measure 2.3, Indicator 5: Criteria that address harvesting and site preparation to protect soil productivity.
- SFI – Performance Measure 2.3, Indicator 2: Use of erosion control measures to minimize the loss of soil and site productivity.
- FCS Draft – Criterion 6.3.1. Appropriate to the scale, intensity and risk of the forest management activities, Management Plans or associated documents (for example Ground Rules, Standard Operating Procedures, etc.) based on best management practices identifying means to protect soils from physical damage. The best management practices related to the protection of soils from physical damage address the following.
    - 1. Prior identification of unstable soils and ground surfaces, and sites sensitive to compaction, rutting, and erosion (for example, wetlands)
    - 2. Avoiding construction of roads and landings on unstable soils and ground surfaces and steep slopes,
    - 3. Constructing and maintaining roads so as to avoid erosion;
    - 4. Use of alternative harvesting and site preparation equipment (for example low ground pressure equipment) and other mitigation measures, such as seasonal timing, and temporary suspension of activities during unfavourable weather to minimize soil rutting and compaction; and

- 5. Identification of precautionary damage thresholds.
- FSC Criterion 6.7.1 Best management practices are in place and being effectively implemented to protect water bodies, riparian zones, and water quality. At a minimum, measures address the following:
  - Measures to prevent sedimentation of water bodies and soil erosion from harvesting, roads construction, maintenance and use;

If harvesting near or in wetlands when the ground is not frozen, plan to use equipment to minimize damage to soil

Government

- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 3.4. Forest Harvest Plan
  - Section 3.4.8 Where applicable the following comments shall be mapped and/or described for each harvest area:
    - Soil protection measures when any of the following are present:
      - Identified areas, water-source areas, springs, or seepages
      - Steep or sustained slopes or grates (>30%)
      - Unfrozen operating conditions.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Table 2. Standards and Guidelines for Operating Besides Watercourses.
  - Water source areas and areas subjected to normal seasonal flooding
    - Road construction, timber harvest, reforestation and reclamation shall be done with equipment capable of operating without causing excessive disturbance to soil layers.

Certification

- SFI – Performance Measure 3.2, Indicator 4: “Plans that address wet-weather events in order to maintain water quality (e.g. forest inventory systems, wet-weather tracts, definition of acceptable operating conditions)”
- FCS Draft – Criterion 6.3.1. Appropriate to the scale, intensity and risk of the forest management activities, Management Plans or associated documents (for example Ground Rules, Standard Operating Procedures, etc.) based on best management practices identifying means to protect soils from physical damage. The best management practices related to the protection of soils from physical damage address the following.
  - 4. Use of alternative harvesting and site preparation equipment (for example low ground pressure equipment) and other mitigation measures, such as seasonal timing, and temporary suspension of activities during unfavourable weather to minimize soil rutting and compaction.

Establish vegetated zones around wetlands

Literature

- When comparing buffer widths across Canada and the USA, the boreal region has the greatest widths (Lee et al. 2004).

Government

- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Table 2. Standards and Guidelines for Operating Besides Watercourses.
    - Water source areas and areas subjected to normal seasonal flooding
        - Treed riparian management zone of at least 20 m on all water source areas

Certification

- FSC Criterion 6.7.1 Best management practices are in place and being effectively implemented to protect water bodies, riparian zones, and water quality. At a minimum, measures address the following:
    - 1. Buffer widths sufficient to protect water quality, aquatic and emergent vegetation and habitat for fish, invertebrates, other aquatic species, and terrestrial

Establish storage and recovery plans for petroleum products and other pollutants

Government

- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 11.6 Camps and Facilities
    - Temporary fuel storage sites shall not be located within 100m of any channelled watercourse.
- Alberta Timber Harvest Planning and Operating Ground Rules Framework for Renewal (AESRD 2012): Section 6. Watershed Protection
    - Section 6.0.7 Sediment, logging debris or deleterious materials (e.g., fuels, oils, greases, industrial or household chemicals or refuse) shall not be deposited in the water or onto the ice of any watercourse or water body during road construction, maintenance, harvesting, reclamation, or silviculture operations.

Certification

- FSC – Criterion 10.6.1. The use of fertilizers is minimized or avoided. When fertilizers are used:
    - 2. Buffer zones are used to protect rare plant communities, riparian zones, watercourses, and waterbodies.
- FSC - Criterion 10.12.1. Ground rules or operational procedures related to handling of chemicals, liquid and solid non-organic wastes, including fuel, oil, batteries and containers are in place and are implemented. The management standards identified in procedures are consistent with high levels of performance and best management practices*. At a minimum the procedures address:
    - 1. Refueling constraints, including buffer around riparian zones and waterbodies
- SFI – Performance Measure 2.2.
    - Indicator 8g. Use of management practice appropriate for the situation, for example, monitoring of water quality or safeguards to ensure proper equipment use and protection of streams, lakes and other waterbodies.
    - Indicator 8h. Appropriate transportation and storage of chemicals
- FSC - Criterion 10.12.1. Ground rules or operational procedures related to handling of chemicals, liquid and solid non-organic wastes, including fuel, oil, batteries and containers are in place and

are implemented. The management standards identified in procedures are consistent with high levels of performance and best management practices*.

- FSC Criterion 6.7.1 Best management practices are in place and being effectively implemented to protect water bodies, riparian zones, and water quality. At a minimum, measures address the following:
  - 8. Measures to prevent impacts from chemicals or fertilizers. (Adapt – from IGI 6.7.1 and 6.7.2)

Minimize invasive species introductions and spread

Certification

- SFI Performance Measure 4.1. Indicator 7. Participation in programs and demonstration of activities as appropriate to **limit the introduction, spread and impact of invasive** exotic plants and animals that directly threaten or are likely to threaten native plant and animal communities.
- FSC Canada Standard (Draft 2): Criterion 10.3.2. A plan to prevent the spread of invasive species introduced by The Organization* is developed and implemented in a timely manner* and/or within The Organization's* sphere of influence*. (Adapt - was IGI 10.3.3)

Government

- Ministry of Environment, Government of British Columbia. 2009. Integrated Pest Management Act and Regulation Vegetation Management on Industrial Sites Sector Review Paper. Accessed August 16 2018 at <https://www2.gov.bc.ca/gov/content/environment/pesticides-pest-management/publications-guides/explanatory-notes&title=Explanatory%20Notes>
- Ministry of Environment, Government of British Columbia. 2018. Forest and Range Practices Act. Accessed August 16 2018 at <http://www.bclaws.ca/Recon/document/ID/freeside/00_02069_01>
- Alberta Environment and Parks, Government of Alberta. 2014. Public Lands Act. Accessed August 16 2018 at <http://www.qp.alberta.ca/1266.cfm?page=P40.cfm&leg_type=Acts&isbncln=9780779754854>
- Biodiversity Branch of the Ministry of Water, Land, and Air Protection, Government of British Columbia. 2004. Invasive Alien Species Framework for BC: Identifying and Addressing Threats to Biodiversity. Accessed August 16 2018 at <http://a100.gov.bc.ca/pub/eirs/finishDownloadDocument.do?subdocumentId=915>

Planning Considerations to Improve

Minimize off highway vehicle use

Scientific literature

- Hinkel, K.M., Eisner, W.R. and C.J. Kim. 2017. Detection of tundra trail damage near Barrow, Alaska using remote imagery. *Geomorphology*. 293: 360-367.
- Arp, C.D. and T. Simmons. 2012. Analyzing the impacts of off-road vehicle (ORV) trails on watershed processes in Wrangell-St. Elias National Park and Preserve, Alaska.

Government and associations

- Government of Yukon. ORVs and Yukon Wetlands. Accessed August 15, 2018 < http://www.env.gov.yk.ca/environment-you/documents/ORVsandYukonWetlands.pdf>
- Meadows, D., Foltz, R., and N. Geehan. 2008. Effects of all-terrain vehicles on forested lands and grasslands. Prepared for the Forest Service, U.S. Department of Agriculture. Accessed February 16, 2018 < https://www.fs.fed.us/t-d/pubs/pdf/ATV/08231811L.pdf >
- British Columbia Ministry of Forests and Range. 2008. Protect our forests and rangeland – off road vehicle use. Accessed February 16, 2018 < http://www.sitesandtrailsbc.ca/documents/off-roading.pdf >
- Alberta Wilderness Association. 2016. Motorized recreation on public lands: Position statement. Accessed February 16, 2018 < https://albertawilderness.ca/wordpress/wp-content/uploads/2015/10/AWA-PS-OHV-Recreation-1987-2016.pdf >

Wetland reclamation

- Lee, P., and S. Boutin. 2006. Persistence and developmental transition of wide seismic lines in the western Boreal Plains of Canada. *Journal of Environmental Management*, *78*(3), 240-250.
- Van Rensen, C. K., Nielsen, S. E., White, B., Vinge, T., and V.J. Lieffers. 2015. Natural regeneration of forest vegetation on legacy seismic lines in boreal habitats in Alberta's oil sands region. Biological Conservation, 184, 127-135.,
- House, M. E. L. I. S. S. A., Vitt, D. H., and R.K. Wieder. 2012. Plant community recovery on "minimum disturbance" petroleum sites compared to burned sites in bogs of northern Alberta. *Restoration and reclamation of boreal ecosystems: attaining sustainable development. Edited by DH Vitt and JS Bhatti. Cambridge University Press, Cambridge, UK*, 202-217.
- Strack, M., Softa, D., Bird, M., and B. Xu. 2018. Impact of winter roads on boreal peatland carbon exchange. *Global change biology*, *24*(1), e201-e212.
- Graf, M. 2009. Literature review on the restoration of Alberta's boreal wetlands affected by oil, gas and in situ oilsands development. Ducks Unlimited Canada.
- Caners, R. T., and V.J. Lieffers. 2014. Divergent pathways of successional recovery for in situ oil sands exploration drilling pads on wooded moderate-rich fens in Alberta, Canada. *Restoration ecology*, *22*(5), 657-667.

Appendix 7 Gaps and Recommendations

This appendix contains supporting literature for the gaps described in Chapter Seven of this report.

Successional dynamics over space and time given historical landscape conditions and projected conditions

Borkenhagen, A., and D.J. Cooper. 2016. Creating fen initiation conditions: a new approach for peatland reclamation in the oil sands region of Alberta.*Journal of applied ecology*,*53*(2), 550-558.

Myers-Smith, I. H., Harden, J. W., Wilmking, M., Fuller, C. C., McGuire, A. D., and F.C. Iii. 2007. Wetland succession in a permafrost collapse: interactions between fire and thermokarst.*Biogeosciences Discussions*, *4*(6), 4507-4538.

Väliranta, M., Salojärvi, N., Vuorsalo, A., Juutinen, S., Korhola, A., Luoto, M., and E.S. Tuittila. 2017. Holocene fen–bog transitions, current status in Finland and future perspectives. *The Holocene*, *27*(5), 752-764.

Oke, T. A., and H.A. Hager. 2017. Assessing environmental attributes and effects of climate change on Sphagnum peatland distributions in North America using single-and multi-species models.*PloS one*,*12*(4), e0175978.

Mitsch, W.J., and J. G. Gosselink. 2015. Wetlands, Fifth Edition. ed. John Wiley & Sons, New Jersey.

Gray, M.J., Hagy, H.M., Nyman, J.A. and J.D. Stafford. 2013. Chapter 4: Management of Wetlands for Wildlife. *USGS Staff – Published Research.* Paper 803.

Schrautzer, J., Sival, F., Breuer, M., Runhaar, H., Fichtner, A. 2013. Characterizing and evaluating successional pathways of fen degradation and restoration. *Ecological Indicators*. 25, 108–120. doi:10.1016/j.ecolind.2012.08.018

Myers-Smith, I.H., Harden, J.W., Wilmking, M., Fuller, C.C., McGuire, A.D., and F.S. Chapin III. 2008. Wetland succession in a permafrost collapse: interaction between fires and thermokarst. *Biogeosciences.* 5: 1273-1286.

Turetsky, M, Mack, M.C., Hollingsworth, T.N. and J.W. Harden. 2010. The role of mosses in ecosystem succession and function in Alaska's boreal forest. *Canadian Journal of Forest Research.* 40(7): 1237-1264.

Klein, E., Berg, E.E., and R. Dial. 2005. Wetland drying and succession across the Kenai Peninsula Lowlands, south-central Alaska. *Canadian Journal of Forest Research.* 35(8): 1931-1941.

Holmquist, J.R. and G.M. MacDonald. 2014. Peatland succession and long-term apparent carbon accumulation in central and northern Ontario, Canada.

Wetlands and forest fire

Benscoter, B. W., and R.K. Wieder. 2003. Variability in organic matter lost by combustion in a boreal bog during the 2001 Chisholm fire. *Canadian Journal of Forest Research.* 33: 2509-2513.

Benscoter, B.W., D. K. Thompson., J. M. Waddington., M. D. Flannigan., B. M. Wotton., W. J. de Groot., and M. R. Turetsky. 2011. Interactive effects of vegetation, soil moisture and bulk density on depth of burning of thick organic soils. *International Journal of Wildland Fire.* 20: 418 – 429.

Day, N.J., S. Carriere, and J.L. Baltzer. 2017. Annual dynamics and resilience in post-fire boreal understory vascular plant communities. *Forest Ecology and Management.* 401:264-272.

Doerr, S.H., R.A. Shakesby., and R.P.D. Walsh. 2000. Soil water repellency: its causes, characteristics and hydro-geomorphological significance. Earth Science Reviews 51: 33-65. Granath G, Moore PA, Lukenbach MC, Waddington JM. 2016. Mitigating wildfire carbon loss in managed northern peatlands through restoration. *Nature Scientific Reports.* 6**:** 28498, doi:10.1038/srep28498.

Hokanson H., Lukenbach M.C., Devito K.J., Kettridge N., Petrone R.M., and J.M. Waddington. 2015. Groundwater connectivity controls peat burn severity in the Boreal Plains. ***Ecohydrology.*** 9: 574-584, doi: 10.1002/eco.1657.

Kettridge N., Turetsky M.R., Sherwood J.H., Thompson D.K., Miller C.A., Benscoter B.W., Flannigan M.D., Wotton M., and J.M. Waddington. 2015. Moderate drop in water table increases peatland vulnerability to post-fire regime shift. *Nature Scientific Reports.* 5: 8063, doi:10.1038/srep08063.

Kettridge N., Humphrey R., Smith J.A., Lukenbach M.C., Devito K.J., Petrone R.M., and J.M. Waddington. 2014. Burned and unburned peat water repellency: Implications for peatland evaporation following wildfire. *Journal of Hydrology.* 513: 335-341, doi: 10.1016/j.jhydrol.2014.03.019.

Lukenbach, M.C., Devito K.J., Kettridge N., Petrone R.M., and J.M. Waddington. 2015. Hydrogeological controls on post-fire moss recovery in peatlands. *Journal of Hydrology.* 530: 408-418.

Lukenbach M.C., Hokanson H., Moore P.A., Devito K.J., Kettridge N., Thompson D.K., Wotton B.M., Petrone R.M., and J.M. Waddington. 2015. Hydrological controls on deep burning in a northern forested peatland. *Hydrological Processes.* 29: 4114-4124, doi: 10.1002/hyp.10440.

Lukenbach M.C., Hokanson K.J., Devito K.J., Kettridge N., Petrone R.M., Mendoza C.A., Granath M., and J.M. Waddington. 2017. Post-fire ecohydrological conditions at peatland margins indifferent hydrogeological settings of the Boreal Plain. *Journal of Hydrology.* 548: 741-753.

Price, J.S., and G.S. Whitehead. 2001. Developing hydrological thresholds for Sphagnum recolonization on an abandoned cutover bog. Wetlands 21: 32–40.Lukenbach M, Kettridge N, Devito KJ, Petrone R, Waddington JM. 2016. Burn severity alters peatland moss water availability: Implications for post-fire recovery. *Ecohydrology.* 9: 341-353, doi: 10.1002/eco.1639.

Thompson D.K., and J.M. Waddington. 2013. Peat properties and water retention in boreal forested peatlands subject to wildfire. *Water Resources Research.* 49: 3651-3658, doi: 10.1002/wrcr.20278.

Thompson, D.K., B.W. Benscoter, and J.M. Waddington. 2014. Water balance of a burned and unburned forested boreal peatland. *Hydrological Processes.* 28: 5954-5964.

Turetsky, M. R., B.D. Amiro, E. Bosch, and J.S. Bhatti. 2004. Historical burn area in western Canadian peatlands and its relationship to fire weather indices. *Global Biogeochemical Cycles.* 18: 1-9.

Turetsky, M.R., B. Benscoter, S. Page, G. Rein, G.R. van der Werf, and A. Watts. 2015. Global vulnerability of peatlands to fire and carbon loss. *Nature Geosciences.* 8: 11-14.

Wieder, R.K., Scott K., Kamminga K., Vile M.A., Vitt D.H., T, Bone., Xu B., Benscoter B.W., and J.S. Bhatti. 2009. Postfire carbon balance in boreal bogs of Alberta, Canada. *Global Change Biology*. 15: 63 – 81.

Zoltai, S.C., Morrissey L.A., Livingston G.P., and W.J. de Groot. 1998. Effects of fires on carbon cycling in North American boreal peatlands. *Environmental Reviews.* 1: 13-24.

Vegetation regeneration success

Pouliot, R., Rochefort, L. and E. Karofeld. 2011. Initiation of microtopography in re-vegetated cutover peatlands: evolution of plan species composition. *Applied Vegetation Science.* 15(3): 369-383.

Groot, A. and B.J. Horton 1994. Age and size structure of natural and second-growth peatland *Picea mariana* stands. *Canadian Journal of Forest Research.* 24(2): 225-233.

Salonen, V. 1990. Early plant succession in two abandoned cut-over peatland areas. *Ecography*. 13(3): 217-223.

Fenton, N.J. and Y. Bergeron. 2007. *Sphagnum* community change after partial harvest in black spruce boreal forests. *Forest Ecology and Management.* 242: 24-33.

Renard et al. 2016. Prescribed burning after clearcut limits paludification in black spruce boreal forest. *Forest Ecology and Management*. 259: 147-155.

Wetland hydrologic connectivity and hydrologic processes

Bocking E., Cooper C., and J. Price. 2017. Using tree ring analysis to determine impacts of a road on a boreal peatland. *Forest Ecology and Management.* 404: 24-30.

Devito K., Hill A., and N. Roulet. 1996. Groundwater-surface water interactions in headwater forested wetlands of the Canadian Shield. *Journal of Hydrology.* 181:127–147.

Devito K., Waddington J., and B. Branfireun. 1997. Flow Reversals in Peatlands Influenced By Local Groundwater Systems. *Hydrological Processes.* 11:103–110.

Devito K., Creed I., Gan T., Mendoza C., Petrone R., Silins U., and B. Smerdon. 2005. A framework for broad-scale classification of hydrologic response units of the Boreal Plains: Is topography the last thing to consider? *Hydrological Processes*. 19: 1705–1714.

Dimitrov D., Bhatti J., and R. Grant. 2014. The transition zones (ecotone) between boreal forests and peatlands: Modelling water table along a transition zone between upland black spruce forest and poor forested fen in central Saskatchewan. *Ecological Modelling.* 274:57–70.

Ferone J., and K. Devito. 2004. Shallow groundwater–surface water interactions in pond–peatland complexes along a Boreal Plains topographic gradient. *Journal of Hydrology.* 292:75–95.

Metcalfe R., and J. Buttle. 2001. Soil partitioning and surface store controls on spring runoff from a boreal forest peatland basin in north-central Manitoba, Canada. *Hydrological Processes.* 15: 2305–2324.

Miller C., Benscoter, B., and M. Turetsky. 2015. The effect of long-term drying associated with experimental drainage and road construction on vegetation composition and productivity in boreal fens. *Wetlands Ecological Management.* 23: 845-854.

Mitsch W.J., and J. G. Gosselink. 2015. Wetlands, Fifth Edit. ed. John Wiley & Sons, New Jersey.

Petrone R.M. 2012. Ecohydrological Implications of Road Construction and Reclamation : Interim Data Report.

Price J., and J.M. Waddington. 2000. Advances in Canadian wetland hydrology and biogeochemistry. *Hydrological Processes.* 14: 1579–1589.

Price J.S., Heathwaite, A.L., and A.J. Baird. 2003. Hydrological processes in abandoned and restored peatlands: An overview of management approaches. *Wetland Ecological Management*. 11, 65–83.

Price J.S., Branfireun B.A., Waddington J.M., and K.J. Devito. 2005. Advances in Canadian Wetland Hydrology, 1999-2003. *Hydrological Processes*. 19: 201-214. doi:10.1002/hyp.5774.

Redding T., and K. Devito. 2008. Lateral flow thresholds for aspen forested hillslopes on the Western Boreal Plain, Alberta, Canada. *Hydrological Processes*. 22: 4287–4300.

Rycroft D., Williams D.J.A., and H. Ingram. 1975. The Transmission of Water through Peat: II. Field Experiments. *The Journal of Ecology.* 63: 557.

Turchenek L. 1990. Present and potential effects of anthropogenic activities on waters associated with peatlands in Alberta. Alberta Environment, Research Management Division.

Tague, C., Band, L., 2001. Simulating the impact of road construction and forest harvesting on hydrologic response. *Earth Surficial Processes Landforms*. 26: 135–151. doi:doi:10.1002/1096--9837(200102)26:2%3C135::AID-ESP167%3E3.3. CO;2-A.

Waddington, J.M., Price, D.T. 2000. Effect of peatland drainage, harvesting, and restoration on atmospheric water and car- bon exchange. *Physical Geography*. 21, 433–451.

Waddington J.M., Morris P.J., Kettridge N., Granath G., Thompson D.K, and P.A. Moore. 2015. Hydrological feedbacks in northern peatlands. *Ecohydrology.* 8**:** 113-127, doi: 10.1002/eco.1493.

Wells C., Ketcheson S., and J. Price. 2017. Hydrology of a wetland-dominated headwater basin in the Boreal Plain, Alberta, Canada. *Journal of Hydrology.* 547:168–183.

Willier C. 2017. Changes in peatland plant community composition and stand structure due to road induced flooding and desiccation. Master's Thesis. Accessed October 15th 2017 from https://era.library.ualberta.ca/files/ccz30pt16h/Willier_Caitlin_N_201706_MSc.pdf

Wetland greenhouse gas dynamics and carbon storage

Lavoie, M., Pare, D., Fenton, N., Groot, A. and K. Taylor. 2005. Paludification and management of forested peatlands in Canada: A literature review. *Environmental Review*. 13: 21-50.

Helbig, M., Chasmer L.E., Desai A.R., Kljun N., Quinton W.L., and O. Sonnentag. 2017. Direct and indirect climate change effects on carbon dioxide fluxes in a thawing boreal forest-wetland landscape. *Global Change Biology.* 23(8): 3231-3248. 0–3. doi:10.1111/gcb.13638

Holden J. 2005. Peatland hydrology and carbon release: why small-scale process matters. *Philosophical Transactions of the Royal Society A Mathematical, Physical and Engineering Sciences*. 363, 2891–2913. doi:10.1098/rsta.2005.1671

Man C.D., Lyons K.C., Nelson J.D., and G.Q. Bull. 2013. Potential of alternate forest management practices to sequester and store Carbon in two forest estates in British Columbia, Canada. *Forest Ecology and Management*. doi:10.1016/j.foreco.2013.05.059

Plach J.M., Petrone R.M., Waddington J.M., Kettridge N., and K.J. Devito 2016. Hydroclimatic influences on peatland CO2 exchange following upland forest harvesting on the Boreal Plains. *Ecohydrology.* in press, doi: 10.1002/eco.1750.

Rooney R.C., Bayley S.E., and D.W. Schindler. 2016. Oil sands mining and reclamation cause massive loss of peatland and stored carbon. *Proceedings of the National Academy of Sciences*. 109, 4933–4937. doi:10.1073/pnas.1117693108

Klapstein S.J., Turetsky M.R., McGuire A.D., Harden J.W., Czimczik C.I., Xiaomei X., Chanton J.P., and J.M. Waddington. 2014. Controls on the rate and age of methane released through ebullition from Alaska peatlands following permafrost degradation. *Journal of Geophysical Research.* 119: 418-431, doi: 10.1002/2013JG002441.

Strack, M., Saraswati, S., Xu, B., Rahman, M.M., Lovitt, J., McDermid, G. 2017. Mitigating greenhouse gas emissions induced by road crossings in boreal peatlands. Poster presented at: COSIA Innovation Summit; March 21-22; Calgary, Alberta.

Tarnocai, C., 2006. The effect of climate change on carbon in Canadian peatlands. Glob. Planet. Change 53, 222–232. doi:10.1016/j.gloplacha.2006.03.012

Tubiello, F.N., Biancalani, R., Salvatore, M., Rossi, S., Conchedda, G., 2016. A worldwide assessment of greenhouse gas emissions from drained organic soils. Sustain. 8, 1–13. doi:10.3390/su8040371